



CLIMAWIN

Technical Summary Report

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CLIMAWIN

- Technical Summary Report

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CLIMAWIN

- Technical Summary Report

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1. INTRODUCTION

The EU CLIMAWIN project, led by a consortium of European SME manufacturers, suppliers and customers of windows and ventilation systems, aimed to address a major market opportunity regarding energy efficient fenestration systems for renovation of residential and commercial buildings.

The project aimed to develop a novel high performance window with electronic operation of an auto-regulated natural ventilation system and electronic insulating night blind powered by solar power.

The Climawin project was primarily aimed at the renovation sector, especially in old buildings which do not have energy efficient ventilation systems.

The Climawin project was a collaboration between Research Partners; Aalborg Universitet, Denmark, Universidade do Minho, Portugal, Designit, Denmark. Fraunhofer-Gesellschaft zur Foerderung der Angewandten Forschung, Germany and the SMEs; Horn Vinduer, Denmark, Rauh Sr Fensterbau Gmbh. Germany, Solearth Ecological Architecture, Ireland.

2. PROJECT TECHNICAL CONTENT

The main technical development work in CLIAMAWIN was concentrated on the following issues:

- Definition of functional requirements
- Development of design methods and tools.
- Determination of optimal glazing configuration
- Application of solar shading/night blind
- Development of ventilation system
- Development of control system, devices and software
- Validation and certification

Each issue is described shortly in the following.

2.1 DEFINITION OF FUNCTIONAL REQUIREMENTS

The work focused on development of functional requirements, which included:

- Ventilation requirements – include requirements to the ventilation valve, to thermal and atmospheric comfort in the room, to air flow rates, to ventilation principle, etc.
- Solar shading/ energy storage / night blind requirements and functionality
- Main control principles and requirements including ventilation control, blind control, zone control, etc.
- Electronic control system and communication requirements and functionality
- Design needs

The work was based on the following window functioning modes:

- heating mode (the air is supplied into the room by passing through the air gap)
- cooling mode combined with a by-pass flow (the air into the room is supplied directly from the outside, meanwhile the air gap in the window is ventilated, but not connected with the room).

2.2 DEVELOPMENT OF DESIGN METHODS AND TOOLS

The Work focused on the development of system design methods and tools for the window and its technical components.

Work includes a sizing methodology for the ventilation component in relation to indoor air quality and thermal comfort.

The work also includes development of a design methodology, which through comparison of the yearly energy performance of different window configurations can assist in the customer/manufacturer in selecting the best solution for the specific case.

2.3 DETERMINATION OF OPTIMAL GLAZING CONFIGURATION

The work focused on analysis and investigation of 15 different window typologies with different pane configurations and glazing types in climates of four European countries (United Kingdom, Denmark, France and Germany) in order to identify the optimum typology with regard to their energy balance and impact on thermal comfort.

Hourly simulations of the heat balance of these windows are conducted on four days representing different typical weather conditions. During the simulation the heating and cooling energy balance of the windows were calculated and the comfort performance was evaluated by inlet air temperature and internal surface temperature of the windows.

2.4 APPLICATION OF SOLAR SHADING / NIGHT BLIND

The work focused on experimental investigations carried out on a ventilated double window under controlled laboratory conditions with a modified Hot Box And an artificial sun. Different solar shading or night blinds are mounted within the air gap. Heat recovery, heat losses by transmittance and ventilation, and effective U-value are evaluated and compared for different configurations of solar shading and night blinds under constant boundary conditions.

Six different configurations are tested: non-ventilated double window without blind, ventilated double window without blind, ventilated double window with normal aluminum blind in opened position, ventilated double window with insulated night blind in closed position, ventilated double window with PCM blind in opened and in closed position.

2.5 DEVELOPMENT OF VENTILATION SYSTEM

The work focused on development of the ventilation system and a new ventilation grill with low pressure losses through the grill, possibility to switch operation mode, possibility for control of inlet air flow and possibility for integration of the grill in the window frame.

Initially preliminary measurements of a prototype window ventilation grill were carried out. They highlighted the needed improvements in ventilation grill technical design and lead to different solutions for motorized grill to be considered.

2.6 DEVELOPMENT OF CONTROL SYSTEM, DEVICES AND SOFTWARE

The work focused on the development of the wireless communication multi-sensor and actuator system that can measure temperature, humidity, luminance, CO₂ and other relevant elements, both indoor and outdoor, with very low power consumption.

Work has also focused on enabling the system to drive actuators for solar shading, night blind and ventilation system, according to a set of algorithms in order to assure maximum comfort and excellent power management in the context of a self-powering solution and energy efficient fenestration system

Finally, work has focused on investigation and development of power harvesting/supply system and enabling coping mechanisms for adverse radio frequency propagation conditions.

2.7 VALIDATION AND CERTIFICATION

The work has focused on baseline analysis and demonstration of the functionality of the window system related to energetic, indoor environment and acoustical aspects as well as validation and certification of the window system according to EU-standards

The tests has included:

- Pretesting of a ventilated window with a natural ventilation system to get the U-Value in dependence of ventilation properties
- Test of U-Values of two final prototypes

- Test of window properties for ventilation, heat transfer, total energy transport and acoustics
- Test of the performance of the whole window system with preheating of air in the air gap through electronically controlled ventilation valves.
- Test of the CO₂ control strategy
- Test in a double climate chamber under various climate conditions (summer and winter), with and without sun simulation to simulate and test functionality of the whole system.
- Transient building simulations to calculate and simulate the energy balance of a whole house with installed "ClimaWin windows" compared to a German reference house.
- Test of the risks using the electronic components as well as the mechanical elements of the windows.
- Test of the risk of condensation and moisture problems

3. DEFINITION OF FUNCTIONAL REQUIREMENTS

3.1 WORKING PRINCIPLE

The working principle of a ventilated window can be divided in three different running modes: heating window, cooling window and the window with the air supply from the outside.

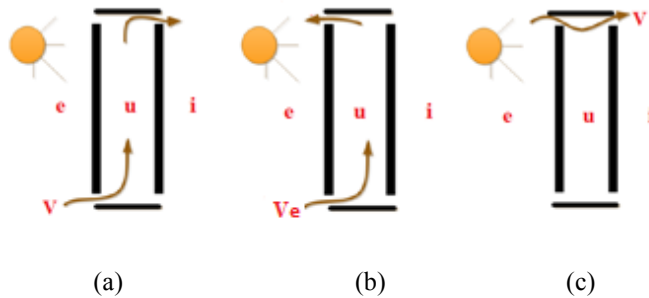


Figure 3.1. Schematic of ventilation mode of a ventilated window. (a) Pre-heating mode (b) External air curtain mode (c) By-pass mode

Heating window (Figure 3.1A)

The main idea behind this window function is minimizing the heating load from the heating system to the room by means of utilization of solar radiation for preheating of ventilation air. Also the energy losses from the room through the inner skin of the window will return back to the room with the ventilation air.

Cooling window (Figure 3.1B)

The goal of this window function is to minimize amount of solar radiation passing through the window. For a traditional window configuration some amount of solar radiation striking the window is absorbed in the glazing panes and then transferred to the room by convection and radiation. Sufficient ventilation of the air gap will cool down the glazing panes and then the heated air can be expelled to the outdoors removing some amount of solar radiation. It must be noted that both cooling and heating effect of ventilation window can increase with installation of solar shading device as will be explained later.

Air supply from the outside (Figure 3.1C)

With this window function the air to the room is supplied directly from the outside. As a result the window will function nearly in the same way as a traditional window. This function is typically can be activated if the air temperature in the gap is too warm to be supplied to the occupied zone or for free cooling purposes if the zone has a cooling need.

Window orientation and the season in the year will contribute (positively/negatively) to window's performance. Actually, windows' functioning requirement will change, depending on window's orientation and season.

In Table 3.1 a summary of the windows expected working principle is given according to its orientation and climatic conditions.

The effect of cooling or heating ability of the window can either be increased or reduced depending on shading device (night blind), its positioning, type, material properties and control strategy.

For an efficient window operation it is necessary to maintain optimal flow conditions in the gap to remove surplus solar heat gains in case of cooling window or to preheat the air effectively before entering the occupied space in case of heating window.

Table 3.1. Overview of window's functional requirement depending on climatic condition and window's orientation

Orientation/Climate	Cold	Cold and Warm	Warm
North	Heating	Heating	Heating
East/West	Heating	Cooling/heating	Cooling
South	Cooling/heating	Cooling/heating	Cooling

Heating – means that the window must minimize need for heating

Cooling – means that the window must minimize need for cooling

Cooling/heating – means that the window must minimize both need for cooling and heating

3.2 FUNCTIONAL REQUIREMENTS

3.2.1 Ventilation

A primary task of a ventilated window is to provide minimum ventilation air flow rates into the occupied zone.

Due to the differences in climate, window orientation, user behavior, etc. there may appear different needs for window function, related to IAQ, comfort and energy use. To fulfill these needs following requirements must be fulfilled:

- Presence of an external air intake valve in bottom of window with filtration and non-return valve
- Two direction air supply valve in top of window
- Air supply valve in the top of window should have bypass, be able to control air flow rate.
- Occupants must not experience draught
- Users must have a possibility for manual override
- Calibration/change of ventilation flow rates must be possible
- Must be possible to use for both natural and mechanical ventilation (must allow small pressure differences)
- Must be possible to achieve optimal ventilation conditions with application of solar shading

By fulfilling the above requirements the window can function as “preheating” air window, as “cooling” window, or a window with the air entering the room directly from the outside. Window function will depend on the direction of supply and/or return air flow in the gap.

Different ventilation principles might be used depending on window orientation, climate and national building regulations in combination with energy considerations.

3.2.2 Solar shading / energy storage /night blind

The properties, type, material and positioning of solar shading/ night blind will define “cooling” or heating solution for a window.

- Selective coatings might be used for the shift between the solar shading and night blind
- Integrated phase change material might be used for preheating air in winter and cooling in summer
- Optimum location of solar shading in the space in relation to ventilation performance and energy efficiency
- Possible use of materials that allow outside view
- Possible use of translucent materials that allow daylight penetration

3.2.3 Control requirements

A control strategy must be developed with following characteristics:

- Ventilation control based on indoor climate (humidity, temperature, occupancy, – zone sensors; solar radiation –device sensor)
- Blind control daytime (in relation to solar radiation and indoor temperature)
- Blind control night time (schedule, outdoor temperature, privacy)
- Wireless sensor communication
- User interface for occupant temporary override
- Possibility for zone control
- Possibility for master/slave window control
- Window must be able to have autonomy regarding the power supply and wireless communication

3.2.4 Main control principles

The main control principles include a ventilation control strategy and a blind control strategy

The ventilation strategy consists of three parts:

- Control of ventilation flow rates depending on indoor air quality and comfort. This is controlled according to a number of sensors:
 - Zone temperature (sensor is placed in the room)
 - Outdoor temperature (sensor is placed on the outer side of the window)
 - Temperature in the gap (sensor is placed in the gap)
 - CO2-sensor or a motion-sensor (it is a zone sensor placed in the room)
 - Humidity-sensor (it is a zone sensor placed in the room)
- Communication control: there must be a possibility for coordination/communication between the window-valve and the ventilation system in the building for a resemblance in supply and exhaust flow rates.
- Control of the flow direction, as there must be a possibility to activate the bypass flow.

The control strategy of the shading device will be defined according to readings from the following sensors:

- Zone temperature (sensor is placed in the room)
- Solar radiation intensity (sensor is placed on the outer side of the window)

This control strategy can be realized by lowering or by raising solar shading device, but also by controlling an angle of the solar shading blinds.

For all of the control levels described above there must be a possibility for the manual control. However, if the user has switched the automatic control system off, then it will not be activated until the user has switched it on manually.

3.2.5 Requirements to the control system elements

The solar cells dimension required for the energy harvesting solution will depend mainly on the type of the actuators and their actuations cycle. The actuators must be energy efficient and also be low power to be driven by the energy harvesting system.

The energy storage mechanism used to store energy to drive the actuators will have a limited electrical power output capability. The blind motors may need some transmission mechanism to increase the gear ratio so that the motors can be used with the low power supply of the system. The control of the blinds must have in consideration if the energy stored is enough to drive the actuators.

4. DEVELOPMENT OF DESIGN METHODS AND TOOLS

There are two main topics that need to be developed in terms of sizing methodology for system components. These are: window energy efficiency and the aspects of indoor air quality and comfort provided by window. The first topic deals with choosing the right window typology for different climatic areas, building use and facade orientation. The second topic on IAQ deals with sizing of the ventilation components to obtain the needed supply air flow rates and the best supply air temperature.

4.1 SIZING OF COMPONENTS FOR INDOOR AIR QUALITY AND COMFORT

The thermal comfort parameter is normally associated with the supply air temperature in the room, in comparison to overall room temperature. For the ventilated window the comfort parameter has a less significance due to the design of the supply air vent in the window, which regulates the amount of the supply air, depending on air temperature in the gap. Such regulation of the supply air flow will influence the supply air temperature during cold season positively, leading to an increase of the supply air temperature. For the hot climates or for periods when the air temperature in the air gap is too high, bypass vent can be activated and the supply air temperature will not be higher than the outdoor air temperature.

The Indoor Air Quality in the building must fulfil the building regulations; therefore the minimum requirement for the supply air flow volume must always be fulfilled. In order to meet these requirements, the supply air vent and the ventilated window must be characterized in terms of different pressure differences and corresponding mass flow rates through the window (air vent). An example of such window characterization is given in Figure 4.1.

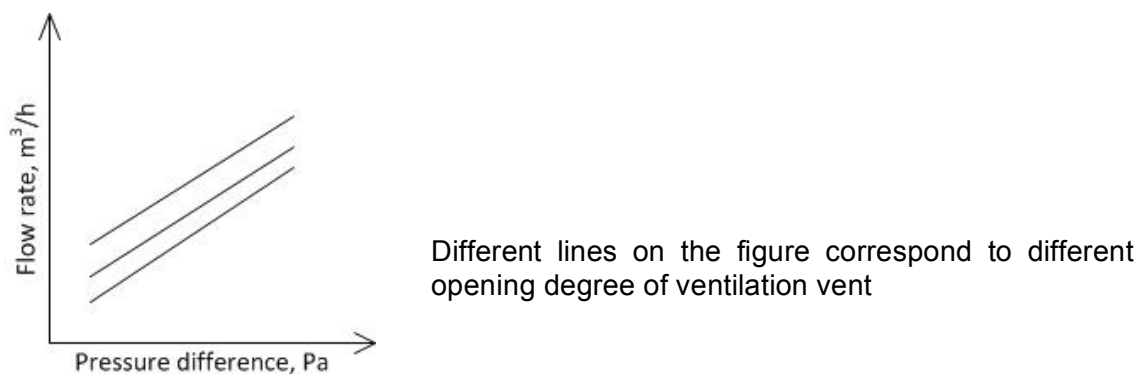


Figure 4.1. Illustration for pressure-flow characterization of window vent.

When knowing pressure losses in the window vent for different flow rates along with the requirements for the fresh air supply into a room/building, it is possible to estimate number of air vents in the window and/or a number of windows to be installed to fulfil the regulations.

4.2 PREDICTING THE ENERGY SAVING POTENTIAL

In order to predict the energy performance and the energy saving potential a simple method is developed, which can be used in the early design phases to predict the thermal behavior of ventilated windows and their impact on building energy performance. As an example of the use of the method the annual energy demand is analyzed in this summary report for a one-family house in typical Danish and Irish

climates. Three types of ventilated windows are compared with a closed cavity window in terms of heat recovery rate and the energy efficiency.

4.2.1 Description of the calculation method

The main basis for the calculation method is EN/ISO 13790, [1], where the calculation of the net heating and cooling demand is described by an energy balance of a building zone, using the elements transmission and ventilation losses as well as solar and internal heat gains.

The referenced method is based on mean monthly values, which can give correct results on an annual basis, but the results for individual months close to the beginning and the end of the heating and cooling season have large relative errors. In order to provide a more detailed and reliable prediction, it is possible to modify this method and perform the calculations on an hourly basis for a design reference year with application of an operation strategy. It is also necessary to split the calculation method between ventilation modes. The ventilated cavity can be regarded as an unheated or uncooled sunspace. Thus the cavity temperature can be calculated by using the DIN V 18599 approach [5]. The calculation method is described in more detail in [Deliverable 4.5].

The ventilated windows will have different thermal behavior and energy performance depending on the ventilation mode.

In the pre-heating mode, the air enters the window cavity at the bottom opening and is supplied to the indoor through the opening located at the top. Normally, the air flow is driven by a mechanical system in the building. The pre-heating mode is commonly used in the heating season.

While, in the external air curtain mode, outdoor air enters the cavity at the bottom and is expelled to the outdoor through the top of the cavity driven by buoyancy and/or wind. This mode can be used to reduce transmission heat gain in the cooling season. However, in order to fulfill the ventilation target, the external air curtain mode needs to cooperate with a by-pass mode, where outdoor fresh air can be supplied directly into the indoor (Figure 4.2). Because of the variety of origin and destination of air flow as well as driving force of ventilation, different calculation methods need to be developed to provide precise and reliable assessment.

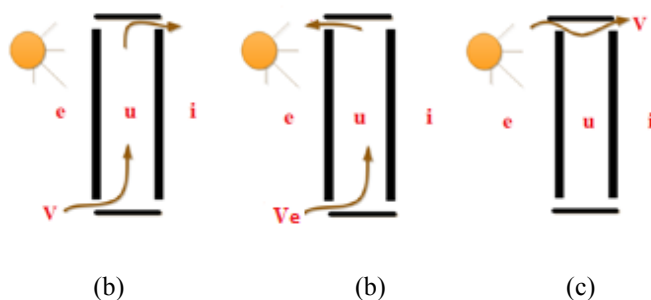


Figure 4.2: Schematic of ventilation mode of a ventilated window. (a) Pre-heating mode (b) External air curtain mode (c) By-pass mode

The performance assessment of ventilated windows with pre-heating mode is slightly easier, because the mechanical ventilation provides constant ventilation rate through the window.

However, for the external air curtain mode with natural ventilation, an unknown influence factor is the ventilation rate going through the cavity. Thus an estimation should be made on the ventilation rate. In this simple tool, a simplified approach developed by University of Lund is adopted [6].

4.2.2 Operation strategy

After establishing the calculation methods for both pre-heating mode and external air curtain mode, the next step is to determine the more energy efficient ventilation mode in each time step. Instead of identifying the ventilation mode by heating or cooling season (monthly or seasonal), a more detail operation methodology is adopted based on the hourly energy performance.

First, in each hour, the energy need is predicted in both ventilation modes. Then, the dominant energy need (heating need or cooling need) of the building is determined. Finally, a comparison is made between the two ventilation modes to determine the most energy efficient one.

4.2.3 Case description

Three ventilated windows and a closed cavity window are analyzed (Figure 4.3). Comparisons are made between these four window types in terms of thermal behavior - heat recovery rate and energy performance.

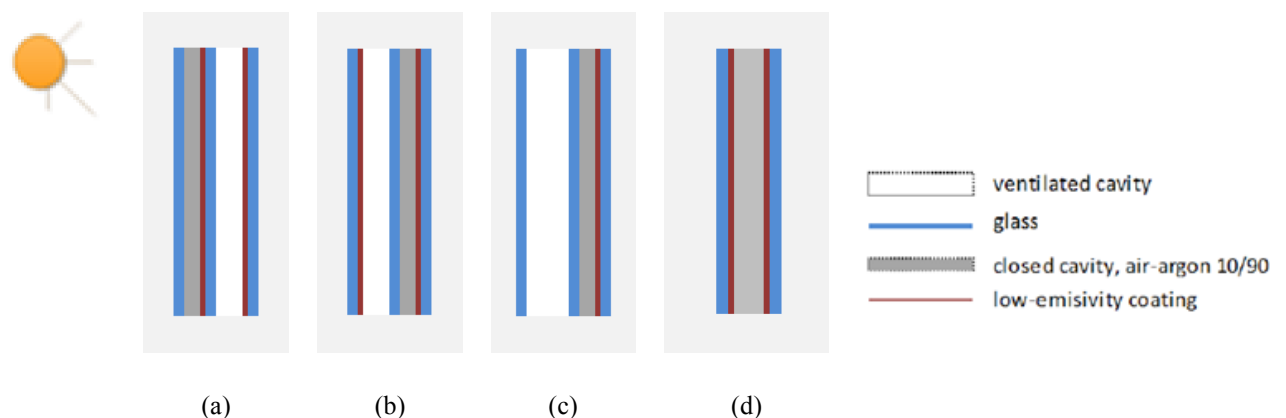


Figure 4.3. Schema of three ventilated windows and a closed cavity window (a) Ventilated window Sample 1; (b) Ventilated window Sample 2; (c) Ventilated window Sample 3; (d) Closed cavity window.

Sample 1 is a ventilated window with double glazing facing outdoor and single glazing facing indoor, which has two layers of low-emissivity coatings. Sample 2 has the opposite configuration of Sample 1, with single glazing facing outdoor and double glazing facing indoor. Sample 7 has similar configuration as Sample 2, the only difference is that just one layer of low-emissivity coating is used. The closed cavity window composes of two layers of low-e glass and the cavity is filled with air-argon gas. T

The main material of the frame is timber. The window properties are calculated by separating the transparent system and the frame. The properties of transparent system are simulated by WIS software in CEN mode. The ventilated window is divided into two parts: internal pane and external pane. The U-value and g-value are calculated for each pane instead of for the whole window, and the influence of the ventilated cavity is not considered in this step (the effect of the ventilation cavity is taken into account in

the calculation method). On the other hand, the property of the frame is simulated by a finite element program THERM, which is shown as the U-value of frame. The window properties are shown in Table 4.1.

Table 4.1: Window properties

Window type	Transparent system					Frame
	U_{ue}	U_{iu}	$g_{L,iu}$	$\tau_{L,ue}$	$g_{L,iu} \cdot \tau_{L,ue}$	U
VW: Sample 1	1.29	5.73	0.635	0.526	0.33	1.01
VW: Sample 2	3.24	1.29	0.63	0.59	0.37	
VW: Sample 3	5.8	1.29	0.63	0.823	0.52	
Closed cavity window	1.2		0.54			

The thermal behavior - heat recovery rate is analyzed and compared between three ventilated windows. All the windows have the same dimension 1.48 m height and 1.23 m width, and a constant air flow rate of 4 l/s is used for all calculations. The energy performance of these four window types applied in a model building is analyzed by the developed method.

The model building is a one family house, which has two floors including a basement, but the basement is treated as an unheated zone, as shown in Figure 4.4. The net volume of the heated zone is 375.1 m³. There are 10 windows in this building, 4 windows facing south, 1 facing north, 3 facing west and 2 facing east. All the windows in the model building have the same dimension 2 m height and 1.625 m width (different dimension from the one used for determining the heat recovery rate). The overall heat transfer coefficients of the building elements are: External wall 0.28 W/(m².K), Roof 0.2W/(m².K), External walls towards soil or wall towards unheated rooms 0.35 W/(m².K) and External door 1.8 W/(m².K).



Figure 4.4. Picture of the one family house

The boundary conditions of the model building are defined based on DIN V 18599 [5]. The set-point temperature of ground floor is 20 °C and the basement is 10 °C. The internal heat source is 50 Wh/(m².d). The infiltration rate of ground floor is 0.07 h⁻¹ and basement is 0.28 h⁻¹. Based on the minimum air change rate of the building (0.4 h⁻¹), the average air flow rate through each window is 4 l/s. In order to simplify the calculation procedure, the usage time of all system is from 0:00 to 24:00, 365 days per year. The calculations are implemented for two climatic conditions: Design Reference Year of Copenhagen, Denmark and Dublin, Ireland.

In order to validate the method, the heat recovery rate and energy performance of the ventilated window are compared with the results of well-known software tools and also with measured results under real conditions.

4.2.4 Verification of heat recovery rate

Calculated values of heat recovery rate

The pre-heating function is normally useful during the heating season, thus, the thermal behavior of the ventilated windows is evaluated for two typical winter days: a sunny winter day and an overcast winter day.

As shown in Figure 4.5, the outlet air temperature is strongly related to outdoor air temperature and solar radiation. During the night or in the overcast day, the outlet air temperature is proportional to outdoor air temperature. However, when solar radiation is present, the outlet air temperature significantly increases and reaches a peak, when the solar radiation is strongest.

Furthermore, it's clear to see that Sample 1 has the highest outlet air temperature among these three ventilated windows. In sunny winter when the incident solar radiation is maximum (494 W/m²), the air temperature rise at the window's outlet is 29.7 °C for Sample 1, while for Sample 2 and Sample 3 it is 19.5 and 18 °C, respectively.

In an overcast winter day or during the night, the air temperature rise of Sample 1 is still higher than Sample 2 and Sample 3. For instance, at 0:00 am on an overcast winter day, the temperature rise at outlet for Sample 1, 2 and 3 is 11.5, 3.4 and 2.5 °C, respectively.

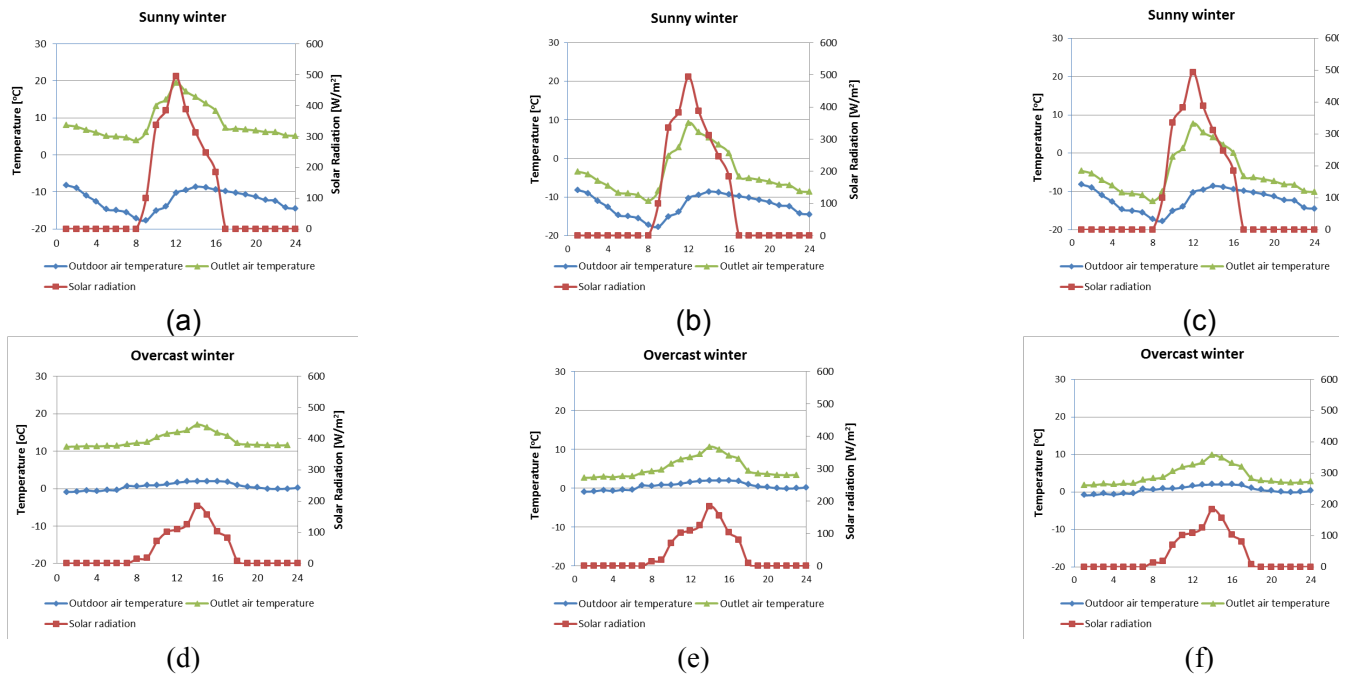


Figure 4.5. Calculated outlet air temperature of ventilated windows in typical climate days (a) Sample 1 in sunny winter day; (b) Sample 2 in sunny winter day; (c) Sample 3 in sunny winter day; (d) Sample 1 in overcast winter day; (e) Sample 2 in overcast winter day; (f) Sample 3 in overcast winter day

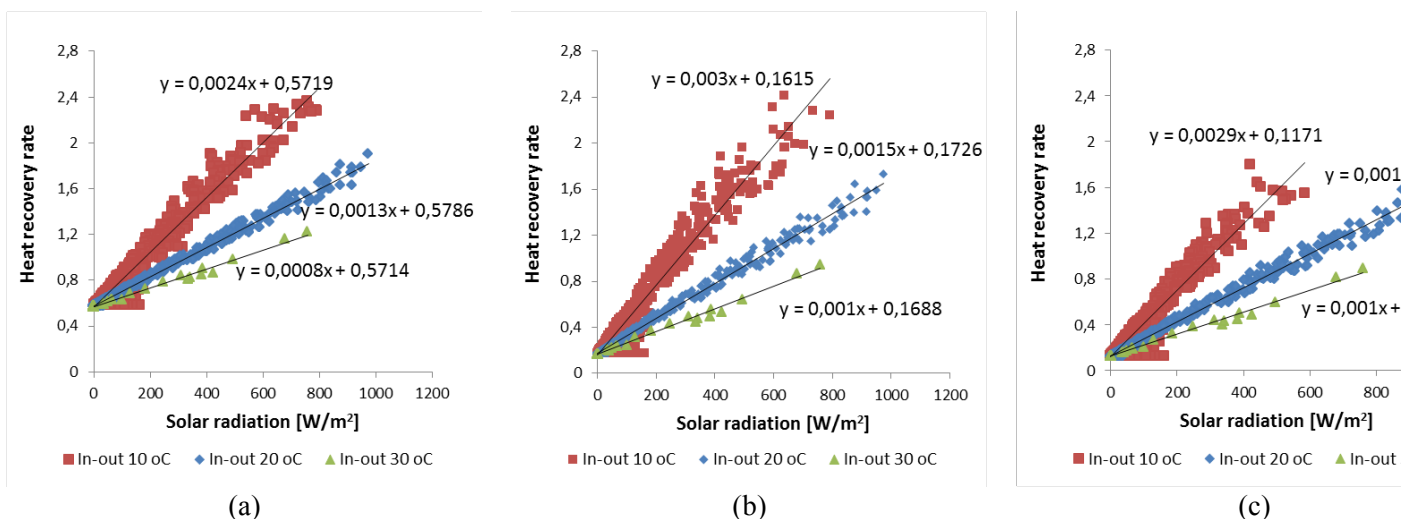


Figure 4.6. Calculated heat recovery rate of ventilated windows as function of direct solar radiation and in-out temperature difference for sample 1 (a), sample 2 (b) and sample 3 (c).

The heat recovery rate is a good indication of the air preheating performance. The higher the heat recovery rate, the warmer outlet air will be. For closed cavity window, the outdoor air is directly supplied into the room, where the heat recovery rate is 0. For ventilated windows, the calculated heat recovery rate is shown as a function of solar radiation for three indoor - outdoor temperature differences, as shown by Figure 4.6.

The correlation between heat recovery rate and solar radiation is strong and a linear tendency. This is because the air is preheated by the solar radiation absorbed by window's components by convection before enters into the room. The stronger the solar radiation, the warmer the air will be. On the other hand, when the solar radiation is 0, a ventilation heat recovery still exists. The value of Sample 1 is around 0.57, Sample 2 is 0.17 and Sample 3 is 0.12. This is because part of the heat loss from building through the window is captured by the air going through the cavity. Thus the supplied air is heated and brings part of the heat into the room again. Therefore, the supplied air is preheated even without solar radiation.

When the solar radiation and the heat loss from building work together, the heat recovery rate strongly depends on the solar radiation. For instance, when the solar radiation is 600 W/m² and in-out temperature difference is 10 °C, the heat recovery rate for these three Samples are all around 2, where the contribution of heat loss from building becomes less important.

The results also show that Sample 1 has larger heat recovery rate than the other two samples. This indicates double glazing facing outside allowing lower thermal loss from indoor and supplying warmer ventilation air into the room, which is an advantage for energy saving and mainly very important for indoor thermal comfort. This performance is also reflected on a yearly basis in Figure 4.7, which shows the cumulative distribution of outlet air temperature for a south facing ventilated window in Danish climate. It can be seen that the outlet temperature of Sample 1 never comes below 5 °C, while the lowest outlet air temperature of Sample 2 and 3 is -12 °C and -15 °C, respectively. Thus, Sample 1 shows clear advantage on reducing the risk of draught for occupant close to the window.

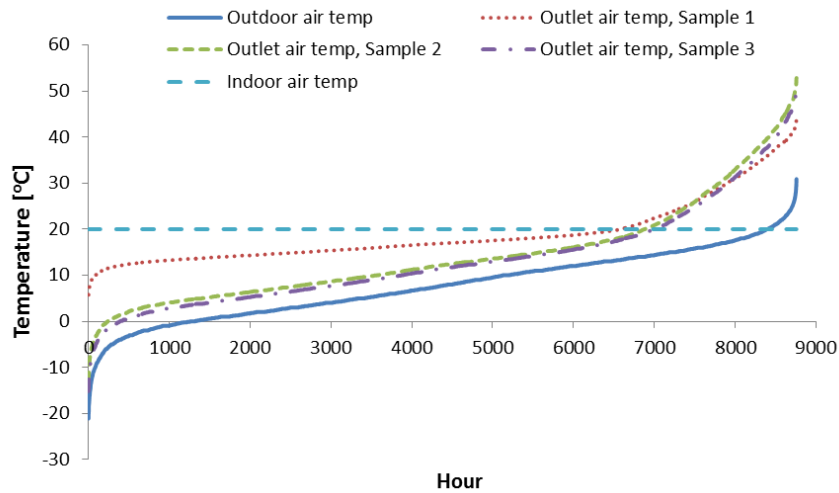


Figure 4.7. Cumulative distribution of calculated outlet air temperature for a south facing ventilated window (DRY Denmark, air flow rate 4l/s).

Comparison with other approaches

Figure 4.9 compares the heat recovery of ventilated window Sample 1 obtained by calculation with the developed method and by WIS simulation and full-scale laboratory measurement. WIS is a well-known software program to determine the thermal and solar characteristics of window systems (glazing, frames, solar shading devices, etc.) and window components. The simulation is done by defining the environment factors and window component parameters. The measurements are carried out with full-scale window under steady conditions, see chapter 6.

The same boundary conditions are defined in these three approaches (Calculation method, WIS and laboratory measurement), where the outdoor temperature is around 0 °C and indoor temperature is around 20 °C. Two solar radiation conditions are studied: 0 W/m² (without sun) and 450 W/m², respectively. The air flow rate through the window is 4 l/s.

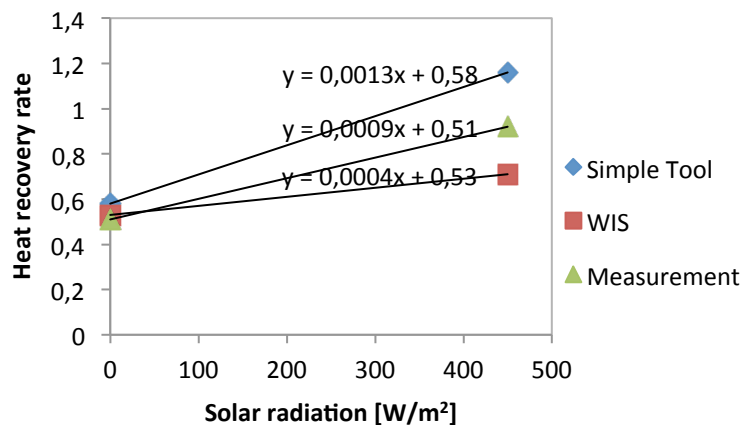


Figure 4.9. Comparison of heat recovery rate by different approaches

Apparently, a good accordance has been achieved in the condition without solar radiation by different approaches. However, when solar radiation (450 W/m²) presents, the results don't match well with each other.

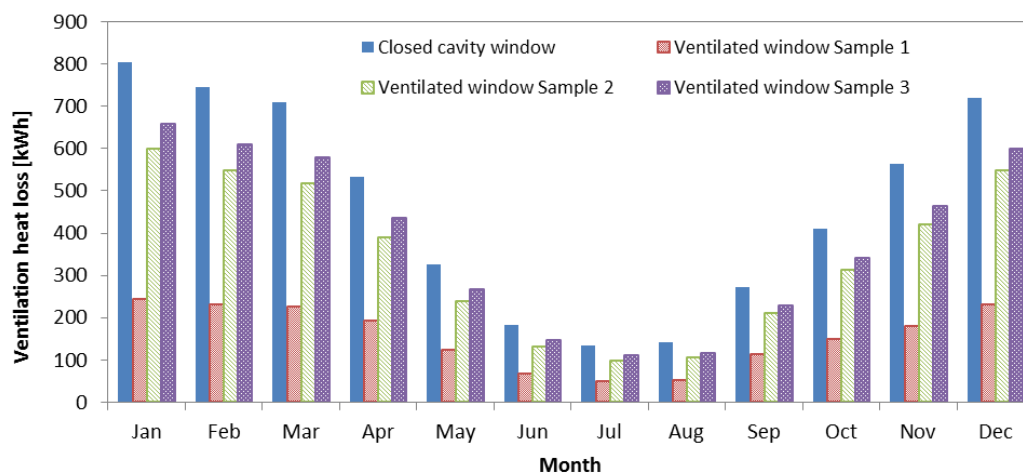
The calculation method predicts the highest heat recovery rate of 1.16, where the deviations to measurement and WIS results are 20% and 39%, respectively. This may

be caused by all the solar heat captured by the cavity is considered to preheat the ventilation air in the calculation approach. While in practice, a part of solar heat is used to heat the glazing and frame. Thus, it seems that the calculation approach overestimates the effect of solar radiation on increasing the air temperature, which results in underestimation of the risk of draught in the space.

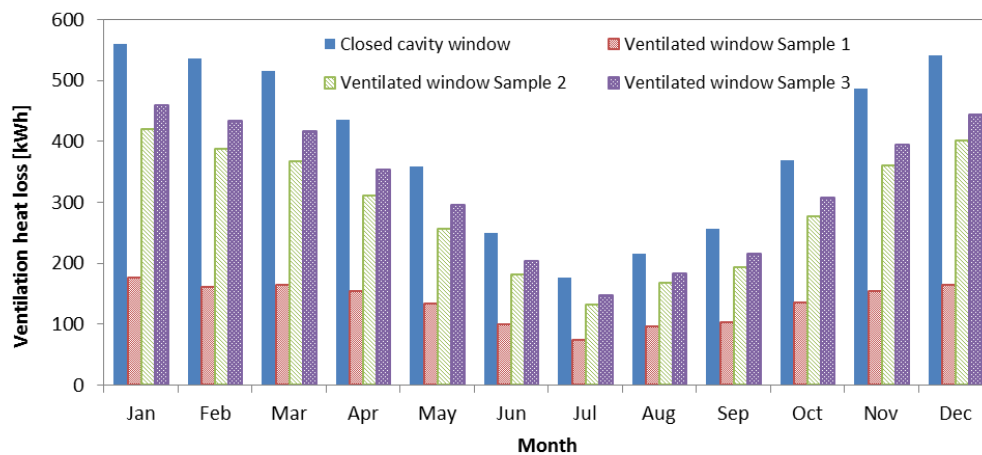
4.2.5 Energy performance

Calculated energy performance

Figure 4.10 compares the monthly ventilation heat loss for 10 windows in the model building, under Danish and Irish conditions. Generally, the ventilation heat loss in Danish climate is larger than that in Irish climate during the heating season, due to its colder outdoor environment. However, the similar trends can be found on the ventilation heat loss between different window types in these two climatic conditions.



(a) Danish Climate



(b) Irish climate

Figure 4.10. Monthly ventilation heat loss for different window types in Danish and Irish Climate

As could be expected, closed cavity window has the largest ventilation heat loss in both weathers due to the lack of pre-heating function. Sample 1 shows the best performance on reducing ventilation loss, where the average reduction of ventilation

heat loss is 65 % in Denmark and 63% in Ireland. Followed by Sample 2 and Sample 3, the average reduction in ventilation heat loss is 26% and 17%, respectively. It can also be observed that the heat recovery performance of ventilated window becomes more efficient, when the indoor- outdoor temperature difference increases. For example, the heat recovery rate of Sample 1 is 69% in January, and it is 58% in September, Denmark.

Table 4.3 presents the yearly energy performance of the model building in a Danish climate, including the energy performance of the windows, the energy performance of the other building elements/systems and the total building energy demands.

Table 4.3. Calculated energy performance of the model building in the Danish climate

Window type	Window				Other building element			Total building energy demands			
	Q_{sol}	$Q_{tr, win}$	$Q_{ve, win}$	$Q_{ts, win}$	$Q_{tr, other}$	Q_{inf}	Q_{int}	Q_H	Q_C	Q_{tot}	Energy demand comparison
	kWh				kWh			kWh			%
Closed cavity window	8260	-3179	-5546	-8726	-11337	-1011	3306	15051	-5589	20640	100%
Ventilated window Sample 1	3915	-3239	-1873	-5112	-11337	-1011	3306	13600	-3190	16790	81%
Ventilated window Sample 2	4418	-2135	-4140	-6274	-11337	-1011	3306	13882	-2913	16795	81%
Ventilated window Sample 3	6084	-2341	-4573	-6914	-11337	-1011	3306	14054	-4214	18268	89%

Beside the heat loss due to ventilation, the energy performance of the window is also influenced by the solar heat gain Q_{sol} and the transmission heat loss $Q_{tr, win}$. It's obvious that the case with a closed cavity window has the largest solar heat gain of 8260 kWh due to its highest window's energy transmittance (g-value or $g_{eff, iu} \cdot \tau_{e, ue}$). As indicated in Equation 4.9, when the other parameters are the same (solar radiation, dimension of window and the frame factor), g-value dominates the amount of solar heat entering the room.

The case with ventilated window Sample 1 has the lowest solar heat gain of 3915 kWh, which is less than half the value of closest cavity window. As mentioned previously, due to the dynamic U-value of the ventilated window, the transmission loss through ventilated window could be regarded as the heat transfer from indoor environment into the window cavity.

For the windows with same dimension, the U-value of internal pane and temperature difference between indoor environment and cavity determine the amount of transmission heat loss. Although the configuration of sample 1 with double glazing outside and single glazing inside provides the lowest indoor – cavity temperature difference, the largest U-value of internal glazing makes sample 1 the largest transmission loss than the other ventilated windows, and even larger than the closed cavity window. The total heat loss from windows is presented by $Q_{ts, win}$, which is the sum of the transmission heat loss from window $Q_{tr, win}$ and ventilation loss $Q_{ve, win}$. Although the large heat transmission increase the heat loss through Sample 1, it could be observed that Sample 1 still has clear advantage over the other window types on preventing heat loss, while the closed cavity window shows the worst performance on heat loss.

The total energy demand of the model building is also determined by other heat sources and heat sinks, such as transmission loss from other building elements $Q_{tr, other}$, infiltration loss Q_{inf} and internal heat gain Q_{int} . Except the windows, the boundary conditions of the model building in different cases are the same. Thus, the results reflect the same energy performance on these parts.

The total energy demand of the model building consists of yearly heating demand and yearly cooling demand, as shown in Figure 4.11. It's obvious that the case with a closed cavity window consumes more energy than the other cases, on both heating and cooling, which reaches around 20640 kWh per year in total.

The ventilated window has an apparent energy saving potential to the closed cavity window. The cases with Sample 1 and Sample 2 have almost the same annual energy demand, which is only 81% of that with closed cavity window. Sample 1 has the lowest heating demand while Sample 2 has the lowest cooling demand, but the difference is not significant. Sample 3 has the worst energy performance among the three ventilated window samples, however, it is still superior to the closed cavity window.

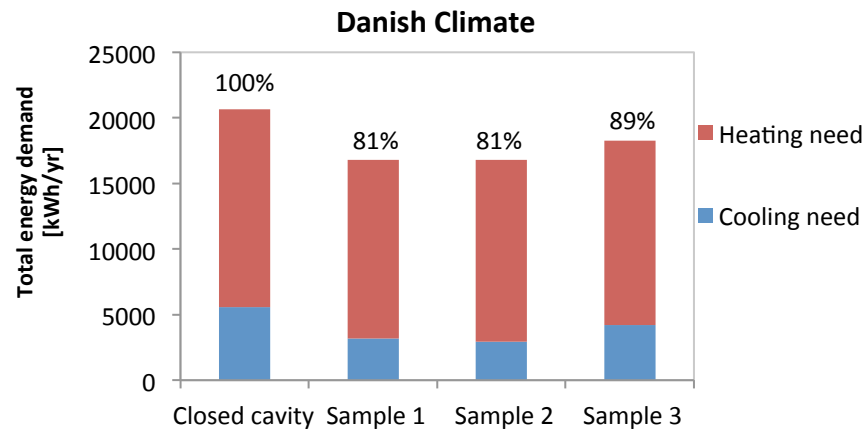


Figure 4.11. Calculated building energy demand with different window typologies in the Danish Climate'

Table 4.4. Calculated energy performance of the model building in the Irish climate

Window type	Window				Other building element			Total building energy demand			
	Q_{sol}	$Q_{tr, win}$	$Q_{ve, win}$	$Q_{ls, win}$	$Q_{tr, other}$	Q_{inf}	Q_{int}	Q_H	Q_C	Q_{tot}	Energy demand comparison
	kWh				kWh			kWh			%
Closed cavity window	7230	-2736	-4704	-7440	-10184	-858	3306	12228	-4343	16571	100%
Ventilated window Sample 1	3384	-2714	-1628	-4343	-10184	-858	3306	11081	-2179	13261	80%
Ventilated window Sample 2	3822	-1798	-3467	-5265	-10184	-858	3306	11331	-2072	13403	81%
Ventilated window Sample 3	5257	-1983	-3866	-5849	-10184	-858	3306	11420	-3130	14550	88%

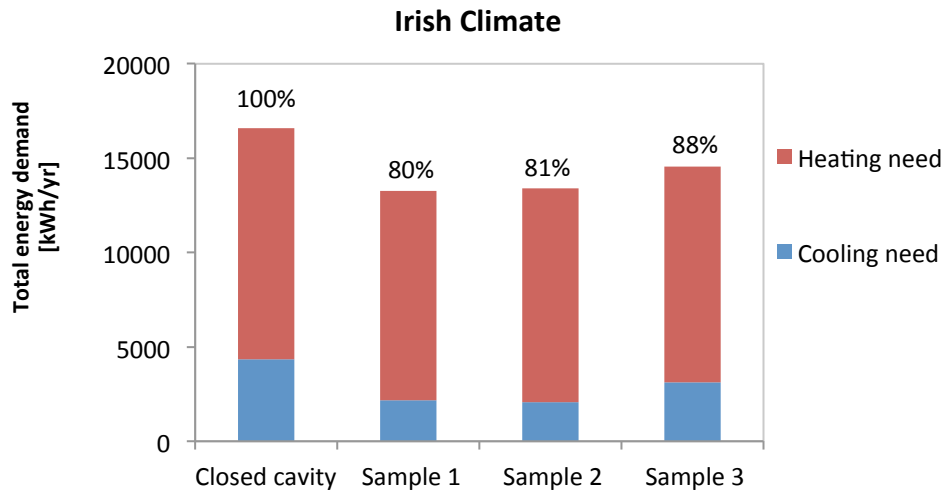


Figure 4.12. Calculated building energy demand with different window typologies in the Irish Climate

The energy performance of the model building in an Irish Climate is presented in Table 4.4. Generally, in an Irish Climate, the energy performances between different window types show a similar trend as in the Danish climate. As illustrated in Figure 4.12, the case with Sample 1 requires the lowest total energy demand of 13261 kWh/yr, followed by Sample 2 of 13403 kWh/yr and Sample 3 of 14550 kWh/yr. The reductions of the building energy demand in relation to the closed cavity window are 20%, 19% and 12%, respectively.

The case with Sample 1 shows the lowest heating demand and the case with Sample 2 shows the lowest cooling demand. On the other hand, the energy demand in the Irish climate is lower than that in the Danish climate, in both heating and cooling need. Denmark is a colder region and the lower outdoor temperature increases the transmission loss, the ventilation loss and the infiltration loss, which enhances the heating demand in the winter season.

In the summer season, solar heat gain is an important factor influencing the cooling demand. The larger solar heat gain in the Danish climate increases the building's cooling need. However, in both the Danish and Irish climate, the heating demand is the dominant energy demand.

Comparison of heating demand with other approach

Table 4.5 presents the building's heating demand in the Irish climate obtained by the calculation method and by TRNSYS simulation. TRNSYS is a fully validated software tool commonly used for building energy simulation. In the TRNSYS models, the thermal behaviors of different window types are distinguished by their heat recovery rates. The impact of ventilation rate on the U-value is not taken into account.

Table 4.5. Heating demand by Simple Tool and TRNSYS

Heating demand [kWh/(m ² .yr)]	Closed cavity window	Ventilated window Sample 1	Ventilated window Sample 2	Ventilated window Sample 3
Approach				
Simple Tool	40,8	36,9	37,8	38,1
TRNSYS	40,3	30,7	37	38,1

These two approaches for determining the heating demand provide good accordance for a closed cavity window. For ventilated window Sample 2 and Sample 3, the deviations are 2.1% and 0%, respectively. The biggest difference appears on ventilated window Sample 1, where the deviation reaches 16.8%. This is due to the TRNSYS modeling approach, where the use of heat recovery rate only takes into account the effect of ventilated window on reducing the ventilation loss.

Actually, as indicated on Table 4.5, although Sample 1 has the best performance on reducing the ventilation loss, its higher transmission loss and lower solar heat gain offset this benefit on reducing the heating demand. Thus, it seems that the chosen TRNSYS modeling approach overestimates the preheating effect of the ventilated window Sample 1.

4.3 CONCLUSION

A simple calculation method has been developed based on hourly energy balance calculations to predict energy performance and thermal behavior of ventilated windows.

The calculation method takes into account two ventilation modes and an operational strategy to determine the more energy efficient ventilation mode based on the outdoor climate. The calculated results of the method are compared with available results from experimental measurements and numerical simulation results by well-known software.

The major deviation on heat recovery rate occurred, when solar radiation influences the ventilated window's performance. The method overestimates the effect of solar radiation on increasing the cavity air temperature. The heating demands obtained by the method and TRNSYS reach good agreement on different window typologies except ventilated window Sample 1. This is because the TRNSYS modeling approach focus on the effect of heat recovery rate and ignores the changes on other window properties. Thus the preheating effect of Sample 1 is overrated.

The performance of different ventilated window types is also investigated. Three ventilated windows are compared with a closed cavity window in terms of heat recovery rate and energy performance. The Sample 1 has the best heat recovery performance compared to the others, which indicates that a ventilated window with double glazing facing outdoor is good for preventing ventilation loss and good for indoor thermal comfort in the heating season.





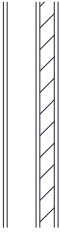





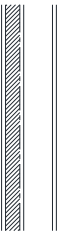


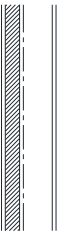

By simulating the energy performance of a model building with 10 windows in different orientations, it's obvious that the energy demand significantly decrease by implementing ventilated windows. The energy saving potential can reach 11% to 20% depending on window typology and climate.

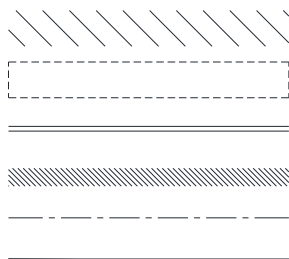
5. DETERMINATION OF OPTIMAL GLAZING CONFIGURATION

5.1 METHOD USED

The investigations were performed on the 15 different window typologies illustrated in Figure 5.1. Typology 3 is a closed cavity window and the others are variations of windows with different pane and glazing configurations and a ventilated cavity. In general the typologies were simulated to test the effect of:

- Coating on a single glazing
- Single glazing outside
- Single glazing inside
- Coating position (surface facing inside or surface facing outside)
- Coating type (solar control or Low-E)

Typ 1	Typ 2	Typ 3	Typ 4	Typ 5	Typ 6	Typ 7	Typ 8
							
Typ 9	Typ 10	Typ 11	Typ 12	Typ 13	Typ 14	Typ 15	
							



Closed cavity, air

Ventilated cavity

Glass

Closed cavity, air-argon 10/90

Low-E coating

Solar control glass coating

Figure 5.1. The 15 different window typologies used in the study.

The ventilation concepts shown in Figure 5.2 are used in the simulation. In summer the active mode is the Cooling mode while in winter the Heating mode is active.

For a traditional window configuration some amount of solar radiation striking the window is absorbed in the glazing panes and then transferred to the room by convection and radiation. Natural ventilation through the air gap can cool down the glazing panes and the heated air can be expelled to the outdoors removing some amount of solar radiation. In addition the air to the room is supplied directly from the outside in the cooling mode.

The main idea behind the heating mode is minimizing the heating load from the heating system to the room by means of utilization of solar radiation for preheating of the ventilation air. Also the energy losses from the room through the inner skin of the window will return back to the room with the ventilation air. The preheating of the ventilation air will also reduce the risk of draught.

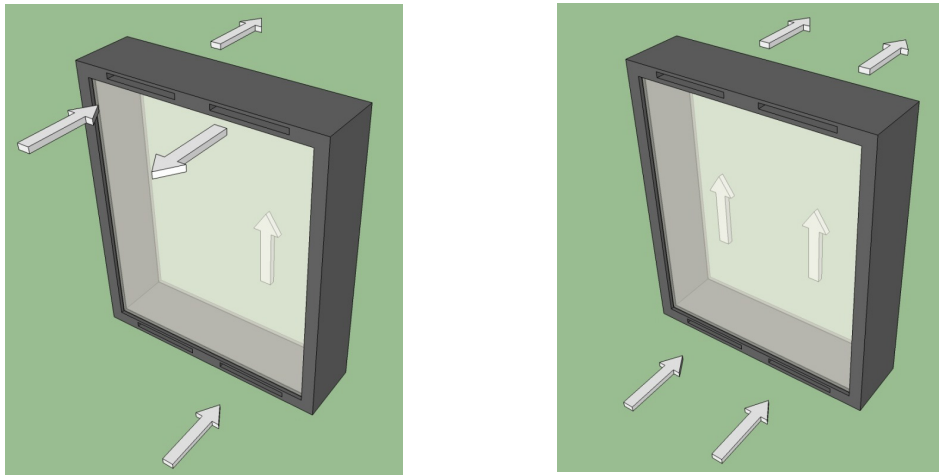


Figure 5.2. Illustration of the ventilation concepts: Cooling mode (left) and Heating mode (right).

Simulation of the window performance have been carried out for three orientations; north, south and west and for four different locations. The locations are Copenhagen (Denmark), Finningley (United Kingdom), Nice (France) and Würzburg (Germany). The results are presented for the individual orientations and discussed. The simulations are performed without solar shading systems.

The weather data is very important for the analysis of the window design and in principle the performance should be evaluated based hourly values for a whole year. However, for a ventilated window both the U-value and the g-value changes hour by hour and it is a very huge task to calculate these values for every hour during a whole year. Therefore, the performance evaluation in this investigation is based on calculations performed for four different typical 24 hour periods, i.e. a sunny summer, an overcast summer, a sunny winter and an overcast winter day.

The methods for choosing the four different days for each of the four different climates are:

- Sunny summer (clear day) - it is chosen to use a 24h-period with a clear sky and with a month-maximum (from 24h-average) temperature for June-July-August.
- Overcast summer - it is chosen to use a 24h-period that include monthly average solar radiation intensity with reasonable part of diffuse solar radiation

and with a monthly average (from 24h-average) temperature for June-July-August.

- Sunny winter (clear day) - it is chosen to use a 24h-period with a clear sky and with a month-minimum (from 24h-average) temperature for December-January-February
- Overcast winter - it is chosen to use a 24h-period that include monthly average solar radiation intensity with reasonable part of diffuse solar radiation and with a monthly average (from 24h-average) temperatures for December-January-February.

The weather data for the four locations can be found in [Deliverable D6.1] .

The evaluation of the window typologies is based on achieving the lowest energy consumption of heating and cooling and the best thermal comfort performance in terms of internal surface temperature and inlet air temperature.

5.1.1 Calculation of the energy consumption

The energy demand for cooling and heating is calculated according to EN/ISO 13790 [1]. The energy balance through the windows is calculated considering heat transmittance, ventilation losses and the solar gain through the windows. Hourly calculations are implemented for all the typical days. It must be noted that the monthly method is modified for hourly calculation, and instead of monthly average weather data the hourly values were used [1]. The calculation method is described in more detail in [Deliverable 6.1].

5.1.2 Estimation of thermal comfort performance

The indoor comfort near the window is evaluated by WIS, which can calculate the average surface temperature of all the window layers and the air temperature at centre and exit position of the cavity.

During the heating mode, the performance of all the typologies is evaluated by the inlet air temperature at the exit of the cavity and the average internal surface temperature of the glazing. During the cooling mode, the performance is evaluated by the average internal surface temperature of the glazing.

The exit air temperature and average internal surface temperature of every typology is the average value of 24 hours. Additionally, the highest hourly internal surface temperature for the sunny summer day and the lowest hourly internal surface and exit temperature of a whole day for the sunny and overcast winter days are presented to compare the comfort performance.

During heating mode, the typologies with the higher exit air temperature have lower internal surface temperature because of the heat transfer from indoor environment to the cavity through internal glazing.

5.1.3 Overall evaluation of window typologies

Each of the selected window typologies has different characteristics, advantages and disadvantages. Some perform well in heating mode, others in cooling mode, while some typologies have an excellent energy performance but provide a poor thermal comfort, etc.

In order to be able compare the different ventilated window typologies, we have defined an overall performance index for each typology by integrating all the performance

parameters of energy and comfort together. The following 14 parameters are picked to calculate the index result:

- Heating energy demand in sunny winter;
- Heating energy demand in overcast winter;
- Cooling energy demand in sunny summer;
- Cooling energy demand in overcast summer;
- Lowest temperature of supplied air in sunny winter;
- Average temperature of supplied air in sunny winter;
- Lowest temperature of supplied air in overcast winter;
- Average temperature of supplied air in overcast winter;
- Lowest temperature of internal surface in sunny winter;
- Average temperature of internal surface in sunny winter;
- Lowest temperature of internal surface in overcast winter;
- Average temperature of internal surface in overcast winter;
- Average temperature of internal surface in sunny summer;
- Highest temperature of internal surface in sunny summer.

Index result values of every parameter are from 0 to 1. For the parameters of energy demand in winter and summer and comfort temperature in summer, the index values are calculated with equation:

$$\frac{\text{Real value of parameter} - \text{The lowest value of all the 15 typologies}}{\text{The highest value of all the 15 typologies} - \text{The lowest value of all the 15 typologies}}$$

For all the parameters of comfort temperature in winter, the index values are calculated with equation:

$$\frac{\text{Real value of parameter} - \text{The highest value of all the 15 typologies}}{\text{The lowest value of all the 15 typologies} - \text{The highest value of all the 15 typologies}}$$

Total index result is the sum of the index values of all the 14 parameters and the best solution is the one with the lowest index.

The equations can make sure that the typology which has lower total index result performs better than the typology that has higher total index result. As the main feature of a ventilated window is the improvement of comfort through preheating of ventilation air, the majority of parameters included in the index are comfort related.

5.2 RESULTS AND DISCUSSION

For all four climatic zones the results of the investigation showed that a ventilated window typology can improve the window performance compared to a traditional closed cavity window. It was also found that solar control glass help to block out solar radiation and thus perform well in summer situations, where overheating must be prevented. In addition, windows with two layers of low-emissivity coatings were found to reduce the energy demand for heating in winter seasons.

All simulations showed that the best energy and comfort performance is obtained when the ventilated cavity is on the interior side of the window. The simulations also showed that the double pane performs slightly better if it has air-argon 10/90 gas in the closed cavity compared to just air and even better with coatings.

According to the calculation, the results of different window typologies have almost the same tendency in different countries and directions, so it is not necessary to show the results of all the countries and for all the directions. Therefore, it has been chosen only to include the calculation results of energy consumption and thermal comfort of the ventilated window typologies facing north in Denmark, facing south in Denmark and facing south in France in the summary report, see figures 5.5, 5.6 and 5.7.

5.2.1 Performance of ventilated window typologies facing south in Denmark

In general the energy demand is the highest for cooling during a sunny summer day and for heating in a sunny winter day for south-facing windows.

Results for low emissivity coating on a single pane (typologies 1 and 2)

The calculated energy performance for typologies 1 and 2 are generally better than that of the closed cavity window and especially in the winter situation the energy performance improves significantly. The results are very similar for typologies 1 and 2. Slightly less energy is used, when the single pane with coating is placed internally (typology 1). For a low-emissivity coating it is preferable to place the single glazing on the exterior side. The small difference in the results can emphasize that the placement can be based on best practice in the final design phase.

From the view point of comfort, typologies 1 and 2 have better performance than that of the closed cavity. And typology 1 has the highest inlet air (cavity exit) temperature, while it has a lower internal surface temperature than typology 2 during the heating mode. But for typology 1 both the internal surface temperatures for a sunny winter day and for an overcast winter day are higher than 14 °C which is above the dew point temperature for normal indoor winter conditions (22°C and 50% RH). During the cooling mode typology 1 has slightly lower internal surface temperature than typology 2.

Results for single glazing on the outside (typologies 5, 6, 7 and 8)

The calculated energy performance for typologies 5 and 6 are worse than for the reference case, but neither of them have coatings on the panes. Typologies 7 and 8 have generally a better energy performance than the reference case with typology 8 as the best one. However, for the sunny summer case typology 7 with a low-emissivity coating needs slightly more energy for cooling than the reference case. In general the performance of low-emissivity coating is best in the winter situation, whereas the solar control glass performs best during summer.

The inlet air temperature of all the four typologies is higher than the reference case, which takes air directly from outside. Typologies 7 and 8 have lower inlet air temperature but higher internal surface temperature than typologies 5 and 6 during the heating mode. For the cooling mode, typologies 7 and 8 have slightly higher internal surface temperature. The highest internal surface temperature during summer days of typology 8 is lower than the others as well as the fluctuation of the internal surface temperature is smaller.

Results for single glazing on the inside (typologies 9, 10, 11 and 12)

The calculated energy performance for typologies 9 and 10 are worse than for the reference case, but neither have coatings on the panes. Typologies 11 and 12 have generally better performance than the reference case with typology 12 as the best one. However, for the summer case typology 11 with a low-emissivity coating needs slightly more energy for cooling than the reference case. The solar control glass in typology 12 has a good effect in reducing the energy demand for cooling in the summer time, but at the same time it increases the heating demand during winter slightly. As found for the

typologies with single glazing inside the low-emissivity coating performs best in the winter situation, whereas the solar control glass performs best during summer.

The inlet air temperature for heating mode for all the four typologies is higher than the reference case, which takes air in directly from outside. Typologies 11 and 12 have both higher inlet air temperature and higher internal surface temperature than typologies 9 and 10 during heating mode. For the cooling mode, typologies 11 and 12 have slightly higher internal surface temperature. The highest internal surface temperature during summer days of typology 12 is lower than the others as well as the fluctuation of the internal surface temperature is smaller.

Results for different coating positions (typologies 13, 14 and 15)

All the results show better performance than the reference case. All results are very similar but the typologies 13 and 14 are marginally better than typology 15. The small difference in results suggests that the placement of the coating should be based on the practical experience, i.e. the coating might be best protected between the double glazing (typology 13) rather than in the ventilated air gap (typologies 14 and 15).

All the results of inlet air temperature are better than the reference case. Typologies 14 and 15 have marginally lower inlet air temperature but slightly higher internal surface temperature than typology 13 during heating mode. For the cooling mode, typologies 14 and 15 have slightly higher internal surface temperature. But the highest internal surface temperature of typology 14 is slightly lower than typologies 13 and 15.

Cross-comparisons between groups

For low emissivity coating on a single pane it is interesting that typology 15 compared to typologies 1 and 2 shows that only one layer of coating on an internally placed single pane performs worse than a combination of two layers of coating, i.e. the low-emissivity coating on the double glazing improves the design in terms of both energy and comfort performance.

For a single layer of glazing outside the typologies 5, 6, 7 and 8 can be compared to typology 2. Typologies 2 and 7 show very similar results, but as stated above two low-emissivity coatings reduces the energy demand. This could indicate that it may be useful to investigate other combinations of low-emissivity coatings maybe in combination with solar control glass. Both typologies 7 and 8 have worse comfort performance than typology 2 during heating mode and cooling mode.

For a single layer of glazing inside the typologies 9, 10, 11 and 12 can be compared to typology 1. Typologies 1 and 11 show very similar results. Again it is found that one layer of coating reduces the energy demand, but two layers enhance the effect. Both typologies 11 and 12 have higher inlet air temperature during heating mode.

Note that the typology 1 with two low-emissivity coatings performs almost as well as typologies 8 and 12 with solar control glass.

The groups with single glazing outside compared to the group of single glazing inside reveal that a single glazing inside generally gives the best energy performance. However, the variations in the results are relatively small, so if other considerations points to a window typology with the single glazing outside this will also be a good solution.

The groups with single glazing outside compared to the group of single glazing inside reveal that a single glazing inside greatly improve the comfort performance in terms of inlet air temperature during heating mode. Typologies with single glazing inside

perform slightly better during the cooling mode in the south and west orientation than typologies with single glazing outside.

Cross-comparison of all window typologies show that the energy demand can be reduced by a window typology with a ventilated cavity in combination with an air-argon filled double pane and a low-emissivity coating or solar control glass.

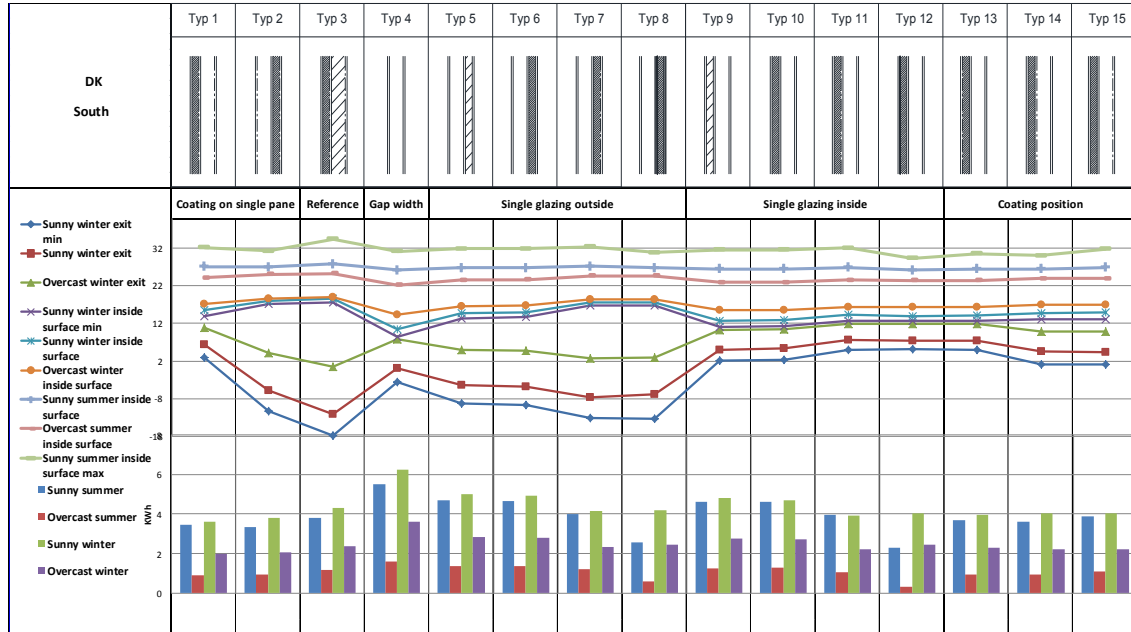


Figure 5.5. Energy demand and thermal comfort results of all the window typologies for south facing orientation in Denmark.

5.2.2 Comparison of performance of window typologies facing south and north in Denmark and facing south in France

Shown in figures 5.5 and 5.6, south-facing typologies in Denmark have higher cooling energy demand than north-facing typologies in Denmark because of the higher solar radiation in sunny summer. Furthermore, the internal surface temperature of all the south-facing typologies are approximately 5 °C higher than that of the north-facing typologies also resulted by the higher solar radiation.

According to figures 5.5 and 5.7, the cooling energy demand and the internal surface temperature of the south-facing typologies in both Denmark and France are high in sunny summer because of the higher value of the solar radiation. The cooling energy demand of south-facing typologies in France, however, is higher than that in Denmark in overcast summer because of the higher outdoor temperature in France. Furthermore, the heating energy demand of south-facing typologies in Denmark is much higher than that in France in sunny winter days, which is because of the lower outdoor temperature in sunny winter in Denmark.

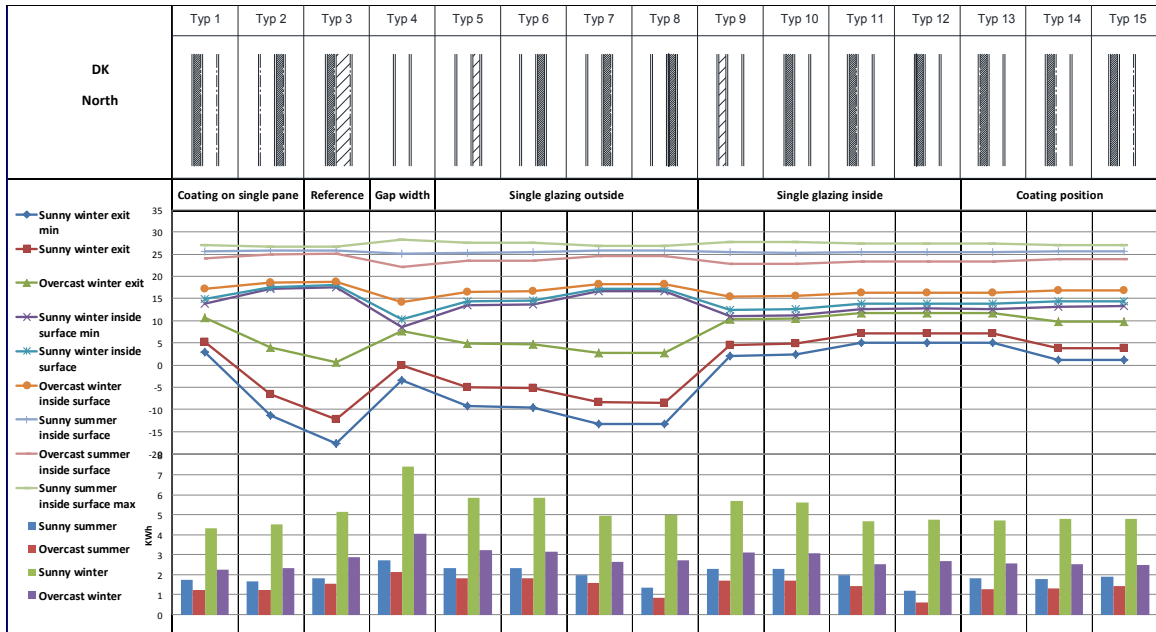


Figure 5.6. Energy demand and thermal comfort results of all the window typologies for north facing orientation in Denmark.

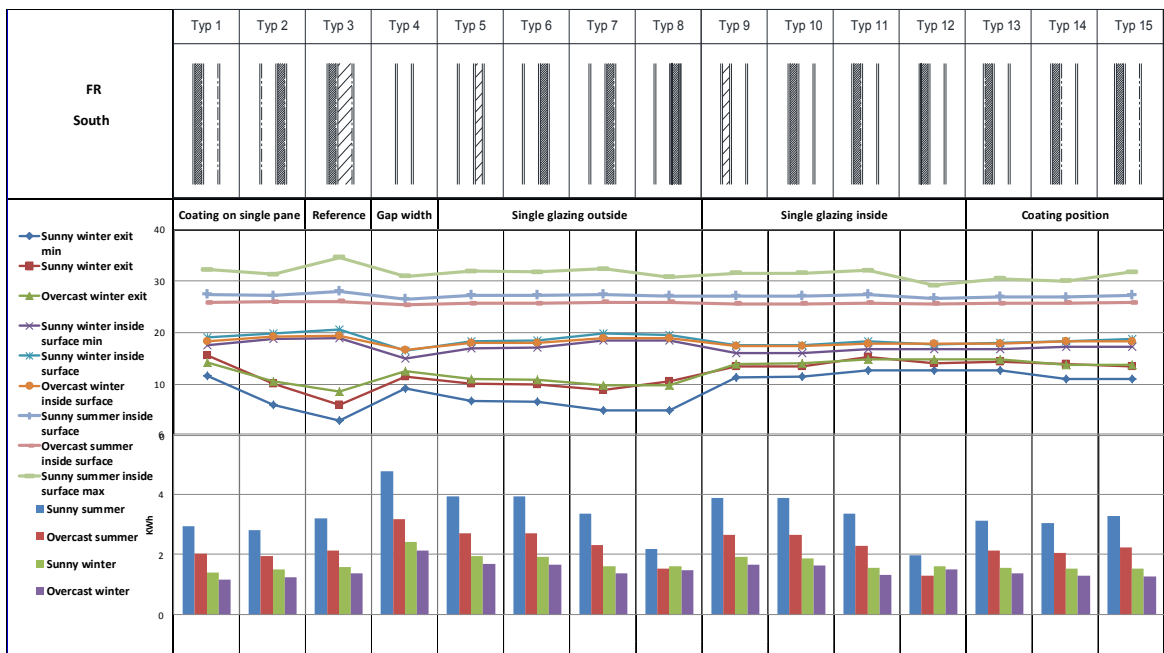


Figure 5.7: Energy demand and thermal comfort results of all the window typologies for south facing orientation in France.

5.2.3 Overall performance evaluation of window typologies

According to the calculated overall evaluation index, see figure 5.8, typology 12 was in general found to be recommendable for all four countries. Typology 12 has an air-argon filled double pane with solar control glass combined with an interior single pane where the gap between them acts as a ventilated cavity. It performs better in terms of the combination of both the energy demand and the indoor thermal comfort. The only exception is in France on north-facing windows. Here typology 1 was found to perform better.

In all the countries, typologies with solar control glazing like typologies 8 and 12 perform worse in north orientation than in the other two orientations, which is reasonable because solar radiation in the north orientation is less problematic than the other two orientations. Therefore, typology 12 with the internal single pane has only slightly lower index value than that of typology 1 for DKN and UKN. The performance of typology 12 does not vary significantly for different orientations in Germany and United Kingdom.

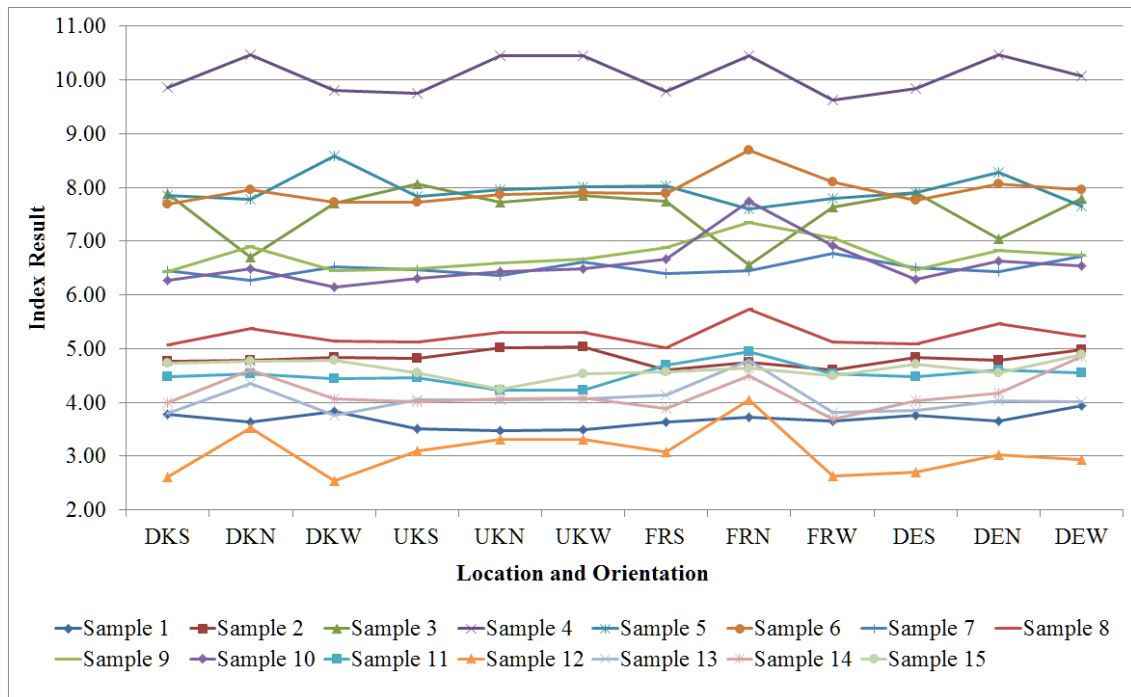


Figure 5.8. Overall evaluation index results of all the window typologies, orientations and climatic conditions.

The current simulations are performed without solar shading systems, so all windows that are exposed to high amount of solar radiation have problems with overheating in summer. This explains why window combinations with solar control glass perform so well in the test.

5.3 CONCLUSION

Based on the different sets of calculations with varying typologies for the windows it can be concluded that ventilated windows can be used to reduce the energy demand for cooling or heating and improve the indoor comfort performance depending on season.

It is recommended to use a window typology like either typology 12 with an air-argon filled double pane with solar control glass combined with an interior single pane where the gap between them acts as a ventilated cavity or like typology 1 with an air-argon filled double pane with a low-emissivity coating combined with an interior single pane also coated where the gap between them acts as a ventilated cavity. And typology 1 and is also recommended because of its better indoor comfort.

The position of the single glazing is preferably at the internal side. It is only slightly better than when the glazing is placed externally in terms of energy consumption, but

the single glazing at the internal side performs much better in terms of the inlet air temperature.

Further research is recommended on combinations of solar control glass and low-emissivity coatings and solar shading systems.

It is also recommended to investigate if it is possible to perform calculations of annual performance for the different window typologies. This could be based on weighting factors for the four days “sunny summer”, “overcast summer”, “sunny winter” and “overcast winter”. This might be useful in order to evaluate how the different window typologies perform on an annual basis.

Another important factor to consider is that the primary energy factors for cooling and heating may differ significantly so this can also influence the final design of the window i.e. it is often preferable to use active heating rather than active cooling.

Finally there are two issues that must be mentioned regarding the results and conclusions in this report:

- Existing performance evaluation of different window typologies regards only their energy efficiency. Within this report it is explained that some of energy-efficient window typologies may have negative impact on thermal comfort. Some of the pilot studies illustrate that energy efficient window configuration, may lead to low glass surface temperatures inside or can offer only low supply air temperatures.
- Typology 12 performs best for almost all window orientations and climates. This is the typology that includes solar control glass and therefore helps to reduce cooling demand during summer. However, most windows will be equipped with movable shading device. In that case, it is useful to continue work with typologies 1 and 2. Finally, window performance may change with installation of solar shading device and therefore it is important to verify performance of preferred window typologies together with shading device.
- It was unexpected that almost the same glazing configuration performs best for all of the climates. Therefore, it is reasonable to expand the criteria for selection of optimal glazing configuration with comfort considerations regarding surface temperature of the glazing and supply air temperature.

6. APPLICATION OF SOLAR SHADING/NIGHT BLIND

An experimental investigation was carried out for different shading devices and night blinds. The fenestration system was placed in a Hot Box modified to integrate an artificial sun and reproducing conditions of a cold winter night or day with clear sky. The air and surfaces temperatures are measured in several places of the system. Thermal performance of each solar shading and night blinds configurations were then evaluated through heat recovery, inlet air temperature, transmittance heat losses, ventilation heat losses and modified total U-value integrating transmittance and ventilation heat losses.

6.1 EXPERIMENTAL SET-UP

6.1.1 Tested ventilated double window

The double window is composed of a ventilated air gap separating an external double glazing window with closed argon-air gap and low emissivity coating from an internal simple glazing window. The inlet air ventilation of the fenestration is located at the bottom of the external window's wood frame and provides external fresh air into the air gap. The air is extracted from the air gap by mechanical ventilation with a constant flow rate of 4 l/s.

Without solar radiation reaching the glazing, the double window works as heat recovering system. During its ascension within the gap, the air is warmed up by heat losses from the indoor environment through the inner window. These heat losses return back inside with the preheated fresh air. With solar radiations, the system works as heat recoverer and solar collector. Solar radiation is absorbed by the frame and glazing panes and transferred to the air while the air is moving up to the top of the ventilated air gap. The outlet air ventilation is located on the top of the inner window's wood frame and provides pre-heated air from the ventilated air gap into the indoor environment.

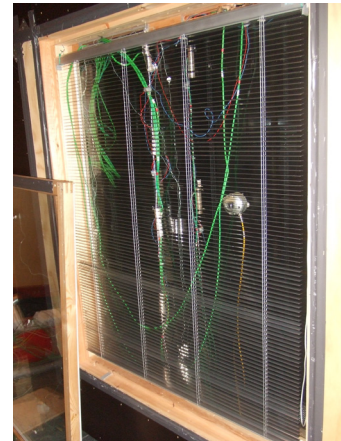
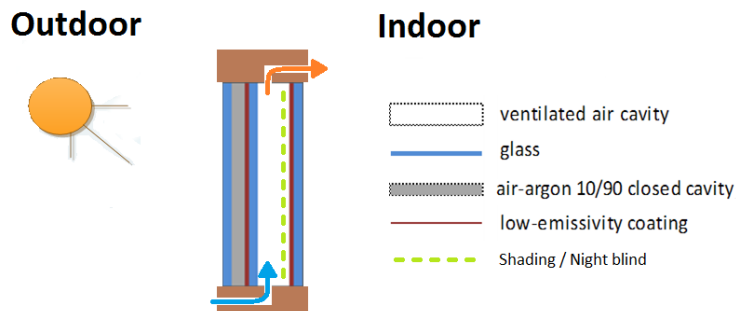


Figure 6.1. Illustration of the ventilated double window

Dimension of the ventilated double window:

Glazing height [m]	1,31	Internal window single pane thickness [mm]	6
Glazing width [m]	1,06	External window external pane thickness [mm]	4
Glazing area A_w [m ²]	1,3886	External window internal pane thickness [mm]	4
Air gap depth [m]	0,074	External window Air-Argon 10/90 gap thickness [mm]	12
Frame area [m ²]	0,2728		
Window area [m ²]	1,6614		

Six different configurations of the double window have been tested under the same controlled conditions:

- Window without shading device and without ventilation of the air gap.
- Window without shading device and with ventilation of the air gap.
- Window with normal shading device in opened position and ventilation of the air gap. The normal shading device is composed of 95 thin grey aluminum blades (15 mm x 1100 mm x 0,2 mm). The device is fully deployed and covers the entire glazing surface of the window. The blinds are in fully opened position (horizontal).
- Window with insulated night blind in closed position and ventilation of the air gap. The insulated night blind is composed of 110 little hexagonal opaque cells (10 mm x 1100 mm x 14 mm). The curtain is fully deployed to cover the whole glazing surface and block entirely the solar radiations. Each cells are covered with an inside silver coating to decrease the thermal losses by radiation.
- Window with PCM blind in opened position and ventilation of the air gap. The shading device is composed of 34 aluminum blades (40 mm x 1125 mm x 7mm). Each blade is filled with Phase Change Material and painted black on one side to get a maximum absorptivity of solar radiations when they are facing the outside and therefor store thermal energy. The blind contain a total of 5,391 kg of ethylene based polymer/paraffin wax (Energain DuPont) with a phase transition at 21,7°C and a total heat storage capacity of 140 kJ/kg [19].
- Window with PCM blind in closed position and ventilation of the air gap. The aluminum reflective surface of the blades is facing the outside and the black side with PCM is facing the inside. When there is no solar radiation anymore, the PCM releases the thermal energy stored during the day into the ventilated air gap and increases the thermal inertia of the entire window.

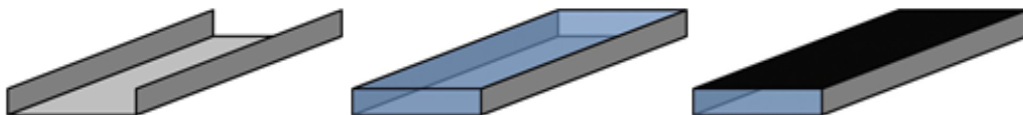


Figure 6.3. Night blind aluminum blade with integrated painted black PCM

6.1.2 Description of Hot Box with artificial sun setup

The goal of this experiment is to recreate a controlled surrounding environment of a window in real life conditions. The stability of indoor and outdoor parameters over the time is a very important issue. A particular attention has been given to keep constant the boundary conditions in order to have a good repeatability of the measurements for each window configuration.

As shown on figure 6.4, the ventilated double window is placed in between the Hot Box part and the Cold Box part and exposed to the solar radiation of the artificial sun.

The Hot Box part simulates indoor conditions of a common house with a set point temperature of 21°C. The air temperature is measured by 4 sensors. A water cooling exchanger and an electric coil controlled by PID controller maintain this temperature between 20,8°C and 21,2°C everywhere in the indoor environment over the time. The ventilation flow rate of the ventilated air cavity is kept constant at 4 l/s.

The Cold Box part creates outdoor conditions of a cold winter day with an air temperature between $-0,5^{\circ}\text{C}$ and $-1,5^{\circ}\text{C}$. The temperature inside the Cold Box part is measured by 3 sensors and kept constant with an air conditioning system with water cooling unit controlled by a PID controller.

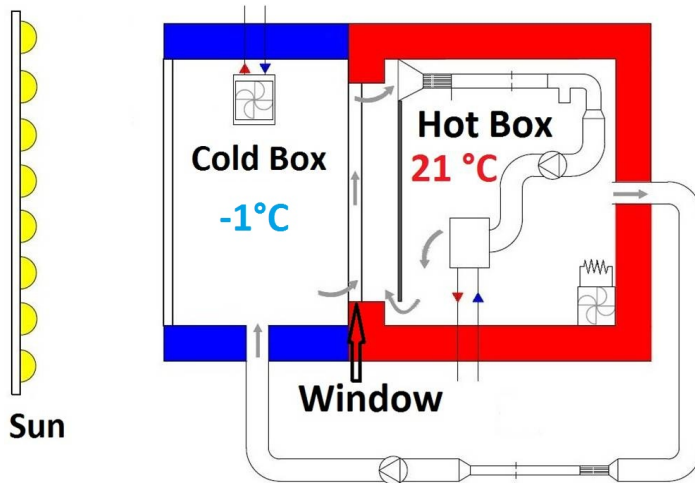


Figure 6.4. Illustration of the Hot Box setup with artificial sun

The side of the Cold Box facing the artificial sun is made of a very clear glazing pane to avoid a high heat gain in the Cold Box but it allows the solar radiation to reach the window. The artificial sun simulates the solar radiations reaching the window by clear sky day. It is composed of 56 OSRAM Ultra-Vitalux 300 W lamp bulbs. The distance between each lamp and between the artificial sun and the fenestration has been tested to give a homogeneous radiation repartition between 440 and 460 W/m^2 on each point of the window's glazing surface. The light spectrum of these lamps is similar to the radiation mixture of natural alpine sunlight. The detailed measurement set-up is described in [Deliverable D6.2].

6.2 MEASUREMENT RESULTS

The six different window configurations have been tested under the same boundary conditions and with the same experimental protocol.

Investigations are carried out on the thermal behavior of the fenestration during four time periods:

- Steady state of a cold winter night without any solar radiation,
- Charging time of the double window with solar radiation during a cold winter day,
- Steady state of a cold winter day with solar radiation
- Discharging time of the double window without solar radiation during a cold winter night.

After 10 hours, temperature in the Cold Box (-1°C), Hot Box part (21°C), and the ventilation rate are stable. The artificial sun is then switched on during about 16 hours. The solar radiations are absorbed by the double window and the air cavity temperature increases rapidly. When the entire fenestration system has reached the thermal steady state, the air temperature in each part of the double window is constant. The artificial sun is then switched off and the temperature of the system decreases to go back to steady state like at the beginning of the experiment.

Figure 6.7 shows an example of the air temperature profile measured during the experimental investigations. In the cases of ventilated air gap, there is a gradient of temperature between the bottom and the top of the cavity. While the air is driven up by the ventilation, it is warmed up by heat losses through the inner window and the solar radiations. Thereby, the gradient temperature is sharply increased when the artificial sun is switched on. In the case of unventilated double window, the air gap temperature is higher and homogeneous.

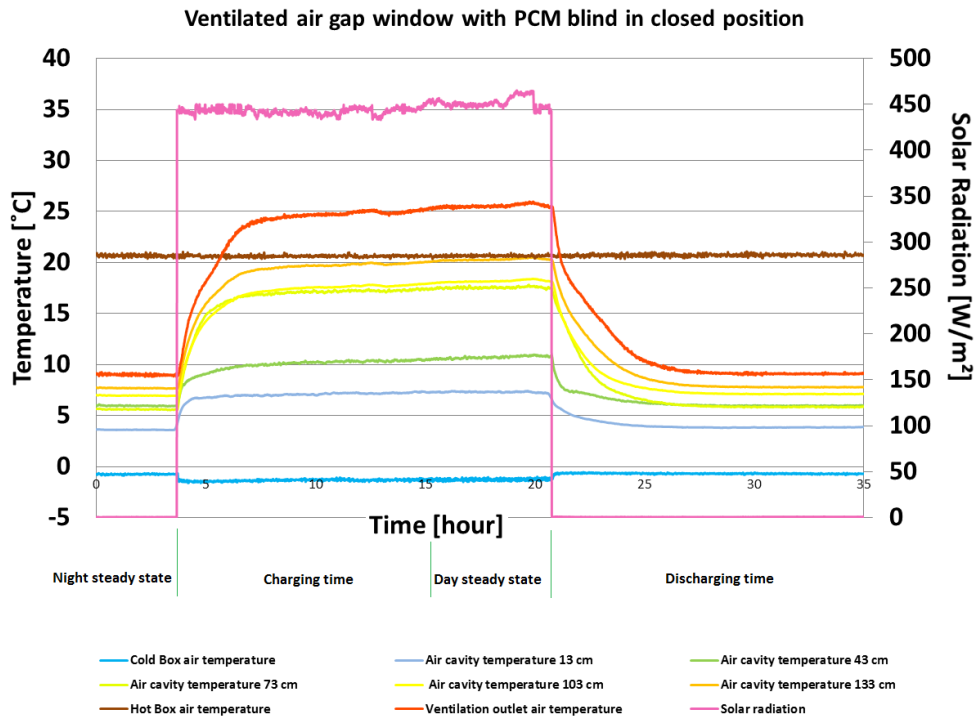


Figure 6.7. Air temperature profile of the ventilated double window

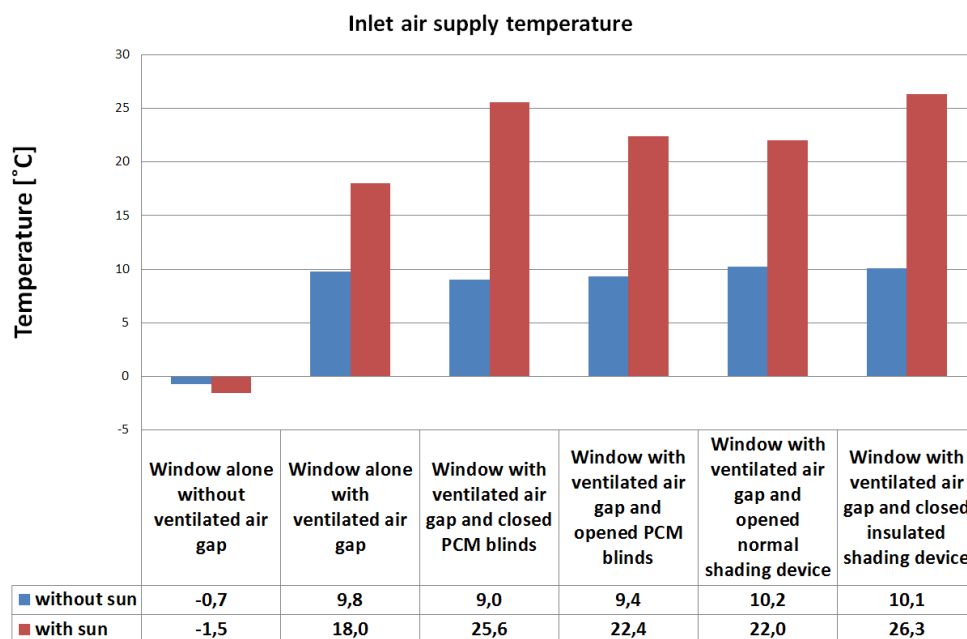


Figure 6.9. The ventilation inlet air temperature on the top of the air cavity

The installation of solar shading or night blinds increases the gap temperature because the absorption of the solar radiations in the air gap is increased.

Figure 6.9 shows the ventilation inlet air temperature of the different window configurations. The unventilated window does not supply pre-heated fresh air thus the inlet air temperature is the same as the outdoor temperature. In the other cases, the inlet air is pre-heated by the heat losses through the inner window during night time (without sun) and also by the solar heat gain during day time (with sun). The installation of solar shading or night blinds increases the air gap temperature and thereby the inlet air temperature.

The glazing surfaces are mainly heated up by the air stream in the cavity. Thereby, the gradient temperature is sharply increased when the artificial sun is switched on. In the case of unventilated double window, the glazing temperature is homogeneous on each pane.

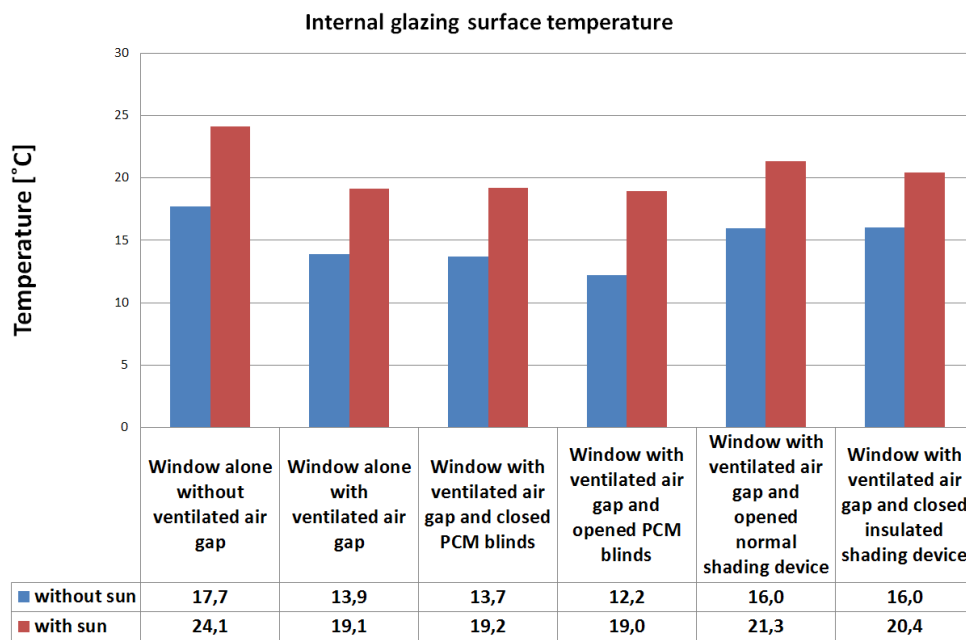


Figure 6.11. The average internal glazing surface temperature of the inner window

Figure 6.11 shows that internal glazing pane temperature is mainly dependent of the air gap temperature. The unventilated window has thus the highest surface temperature. The other configurations show an increase of air gap temperature and thus glazing temperature if solar shading or night blinds are added in the cavity.

6.3 WINDOW PERFORMANCE (ANALYSIS OF MEASUREMENT RESULTS)

The thermal performance of the six different fenestration configurations is evaluated by calculating the heat recovery rate of the window's ventilation, ventilation heat losses, transmittance heat losses, effective U-value during charging and discharging time of the system.

6.3.1 Heat recovery of the window :

The heat recovery is a good indication of the inlet air pre-heating system performance. It is calculated as shown in Equation 6.1 with $\theta_{outdoor}$ and θ_{indoor} of respectively about -1°C and 21°C :

Equation 6.1

$$\varepsilon = \frac{\theta_{inlet} - \theta_{outdoor}}{\theta_{indoor} - \theta_{outdoor}}$$

If the temperature of the inlet supplied air is lower than the indoor environment air temperature, the heat recovery is lower than 1. If the heat recovery is higher than 1, the inlet supplied air is over heated compared to the indoor set point temperature.

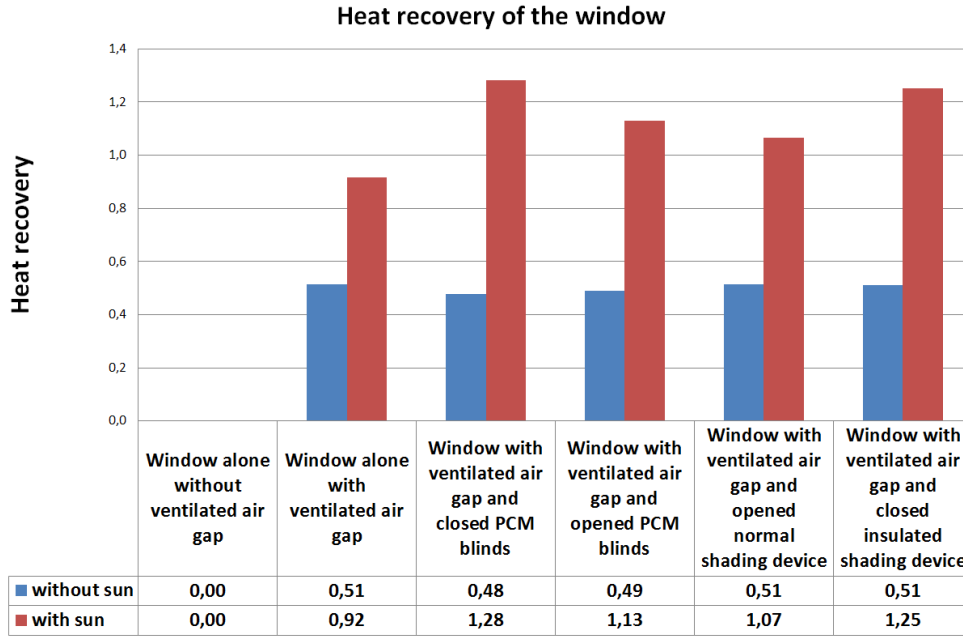


Figure 6.12. Sum up of heat recovery rate for each window configuration

In the case of non-ventilated window, the ventilation inlet air is coming directly from the outside at the same temperature as the outdoor environment. Therefore, the heat recovery is equal to 0. Figure 6.12 shows that the heat recovery is very similar in every cases of ventilated window because the inlet air is only pre-heated by heat losses through the inner window. Under solar radiations, the heat recovery is increasing sharply. The wooden frame, the solar shading or night blind and the glazing panes are heated up and then warm up the surrounding air in the cavity. Without sun, the ventilated double window therefor supplies half of the energy necessary to warm up inlet fresh air at the indoor set point temperature. With solar raditions, almost all the energy is supplied from solar heat gain or even more in the window configurations with solar shading or night blinds.

6.3.2 Ventilation heat losses of the window :

When the inlet supplied fresh air has a lower temperature than the indoor air temperature, heat energy is needed to warm it up to the indoor set point temperature θ_{indoor} of 21°C. This energy is counted as ventilation heat losses as shown in the previous equation with a ventilation rate φ_{vent} of 4 l/s :

Equation 6.2

$$Q_{vent} = \rho_{air} \times C_{p\ air} \times \varphi_{vent} \times (\theta_{indoor} - \theta_{inlet})$$

The average value of ventilation heat losses is calculated for each phase of the experiment: steady state without sun, charging time of the window with the sun turned on, steady state with sun and discharging time of the window without sun. Figure 6.13 shows that ventilation heat losses are significantly decreased with air gap ventilation compared to non-ventilated window configuration. The losses are divided by two when

there is no sun, and totally suppressed in the case of ventilated windows with solar shading or night blinds. Heat losses are negative when there is an over-heating of the inlet supplied air compared to the indoor set point temperature.

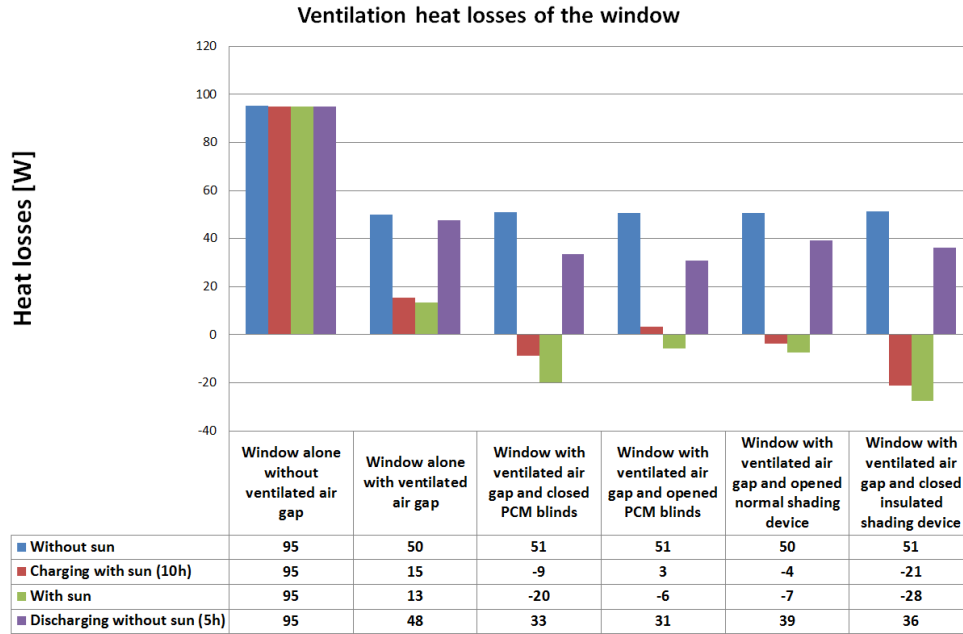


Figure 6.13. Sum up of ventilation heat losses for each window configuration

6.3.3 Transmittance heat losses of the window :

The transmittance heat losses of the double window are calculated between the indoor environment and the air cavity, through the simple pane internal window. The calculation is based on the U-value calculated by WIS simulation and the measured average air temperature difference between the air cavity and the indoor environment. This U-value (U_w) is equal to 5,73 W/K.m². The transmittance heat losses are calculated with Equation 6.3.

Equation 6.3

$$Q_{trans} = U_w \times A_w \times (\theta_{indoor} - \theta_{gap})$$

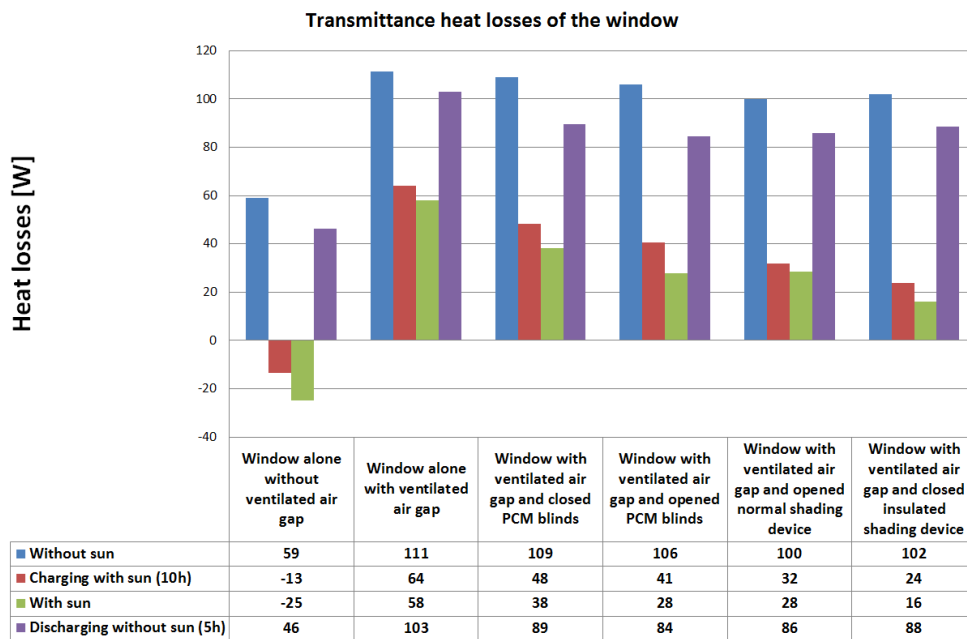


Figure 6.14. Sum up of transmittance heat losses for each window configuration

The average value of transmittance heat losses is calculated for each four phase of the experiment. Figure 6.14 shows that the non-ventilated window has the lowest transmittance heat losses because its non-ventilated air cavity reaches higher temperature and so is a better thermal insulation from the outdoor environment. The heat losses are even negative when the cavity air temperature is higher than the indoor temperature and thus the air gap is heating up the inside environment. In the cases of ventilated window configurations with solar radiations, the transmittance heat losses decrease if there is solar shading or night blinds increasing the average air gap temperature.

6.3.4 Total transmittance and ventilation heat losses of the window :

To evaluate the thermal performance of a ventilated window, it is not relevant to only consider the heat losses by transmittance. Therefor, total heat losses due to transmittance and ventilation are evaluated for each window configuration. The average value of total heat losses is calculated for each four phase of the experiment according to Equation 6.4.

Equation 6.4

$$Q_{tot} = Q_{trans} + Q_{vent}$$

Figure 6.15 shows that without solar radiation, the total heat losses are similar for every different configurations. Indeed, the lower transmittance heat losses of the non-ventilated air gap window is compensated by higher ventilation heat losses and the contrary for ventilated double window configurations. But when the window is exposed to solar radiations, configurations with ventilated air gap and solar shading or night blinds have a significant lower heat losses compared to non-ventilated window and ventilated window without solar shading or night blinds. The ventilation heat losses are thus sharply reduced and so the total heat losses.

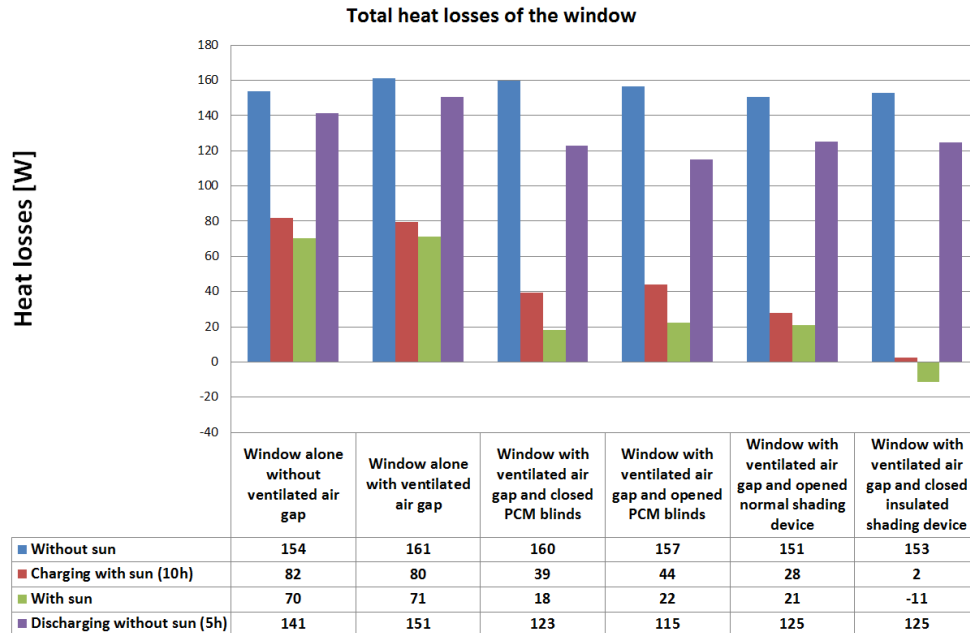


Figure 6.15. Sum up of total heat losses for each window configuration

6.3.5 Effective U-value of the window :

In order to make a better evaluation of the performance of the double window, effective U-value is calculated taking into account total heat losses by transmittance and ventilation according to Equation 6.5.

Equation 6.5

$$U'_{tot} = \frac{Q_{trans} + Q_{vent}}{A_w \times (\theta_{indoor} - \theta_{outdoor})}$$

Effective U-value of the window

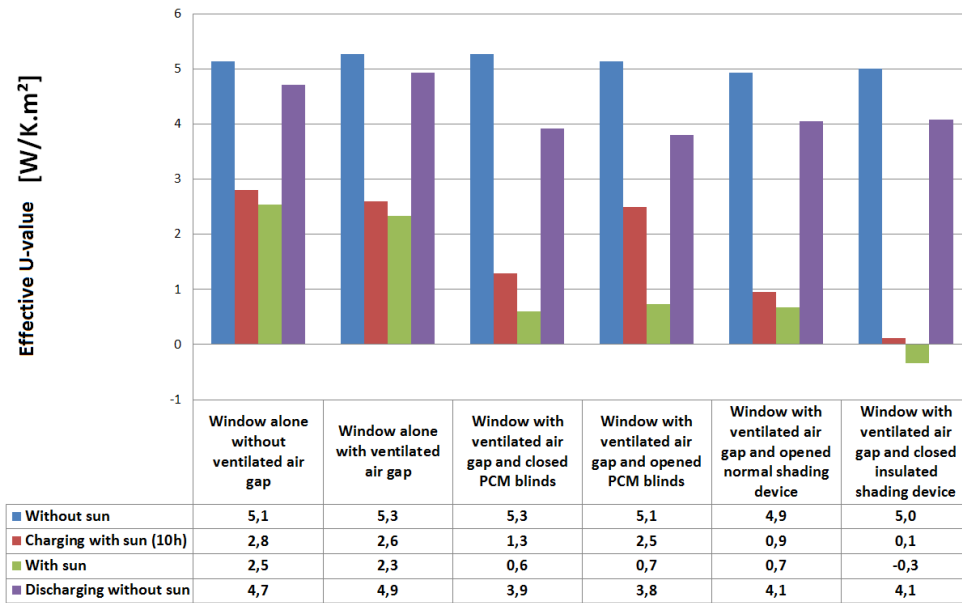


Figure 6.16. Sum up of effective U-value for each window configuration

Figure 6.16 shows that the effective U-value of every configuration is very similar without any solar radiation, because the double window works only as heat recovering system. With solar radiations, fenestrations with ventilated air cavity and solar shading or night blinds decrease significantly their ventilation heat losses and thus their effective U-value.

6.3.6 Energy stored by the window system :

Total heat losses difference is calculated between the non-ventilated air gap window and the other configurations during the discharging time (8 hours after the sun is turned off). Comparison of energy storage capacity is thus made between ventilated windows and the unventilated one. Transmittance and ventilation heat losses are integrated over the time in order to evaluate the energy «saved» by the advanced configurations when there is no radiation reaching the window.

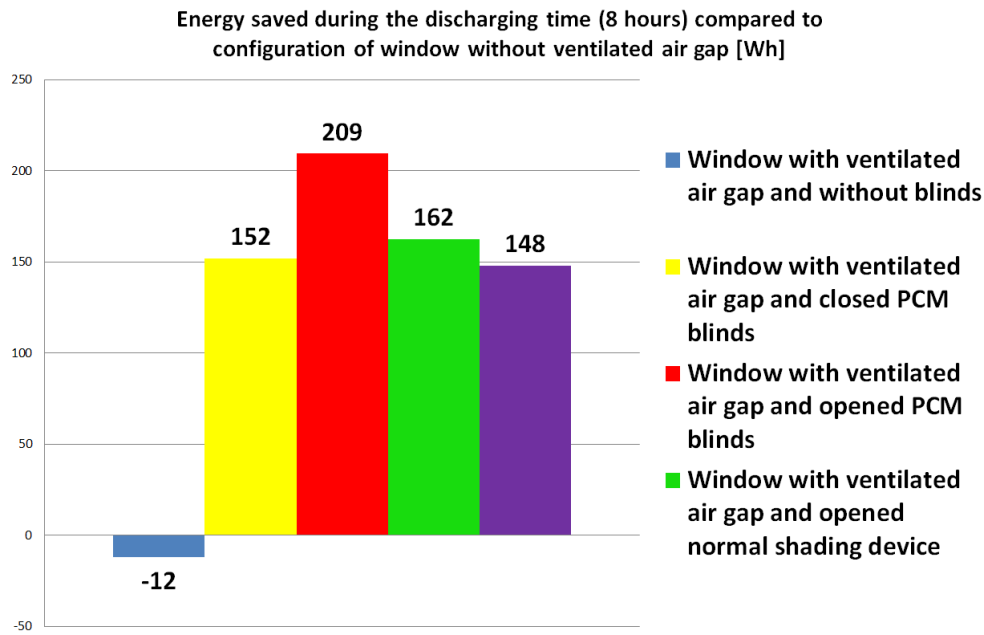


Figure 6.19. Stored energy difference during discharging time for each window configuration

Figure 6.19 shows that ventilated air gap windows with solar shading or night blinds are more energy efficient during the discharging time compared to the unventilated configuration. The differences in the stored energy released during the discharging time are due to the fact that each configuration has different transmittance heat losses but also different inlet air temperature and so difference amount of energy stored in the air gap.

6.4 CONCLUSIONS

This study shows the advantage of a ventilated double window used as a passive air pre-heating system to reduce the energy needs of a building due to ventilation. The pre-heating of the air also increases the thermal comfort by introducing fresh air warmer than the outdoor environment and thus avoids local discomfort caused by draft.

The ventilated air cavity fenestration is more thermally efficient than the non-ventilated one because of the significant drop of total ventilation heat losses when exposed to solar radiations.

This pre-heating capacity is improved by the placement of light regulation system such as solar shading in the ventilated gap.

Solar shading blinds filled with PCM increases the thermal inertia of the ventilation fenestration system. Nevertheless, the amount of PCM does not allow thermal energy storage during the day time important enough to improve significantly the ventilation heat losses during the discharging time by releasing the accumulated heat. The thermal inertia of the whole window system is affected by the addition of PCM as shown on the time delay to reach thermal steady state during transition phases of the experiment. But the amount of stored energy is not significant enough to show important difference in the energy efficiency.

The other ventilated windows with solar shading have higher air gap temperature and thus smaller transmittance and ventilation heat losses.

7. DEVELOPMENT OF VENTILATION SYSTEM

Development of the ventilation system is essential for the performance of the ventilated window. A new ventilation grill was developed with low pressure losses through the grill, possibility to switch operation mode, possibility for control of inlet air flow and possibility for integration of the grill in the window frame.

7.1 FUNCTIONAL CHARACTERISTICS

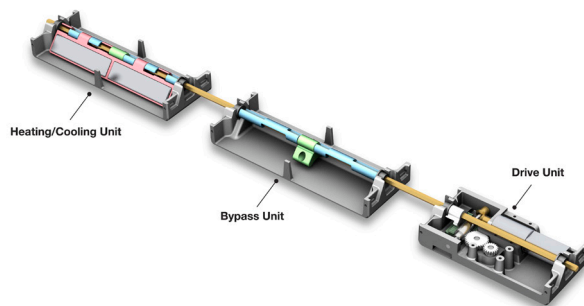
The ventilation grille must comply with a number of requirements.

- Possibility for two direction air supply in top of window (switch between heating and cooling mode)
- By-pass of air in the top of the window
- Low pressure loss for application with both natural and mechanical ventilation
- Possibility for manual override
- The air flow rate can be controlled.

By fulfilling the above requirements the window can function as “preheating” air window, as “cooling” window, or a window with the air entering the room directly from the outside.

7.2 PROTOTYPE SOLUTION

The prototype solution is based on division of the ventilation valve in three units; two functional valve units and one drive unit. The functional units are



Heating/Cooling Valve.

This valve section allows air to go from the bottom of window, through the gap between windowpanes to either the inside – or to the outside.

Bypass valve.

This section is a valve that governs airflow at the top of the window directly between the outside and the room. It has no connection with the gap between windowpanes.

Drive Unit

The Drive unit is a motorised actuator, that provides a rotational force to move the valve flaps of the two functional units.

The separation in functional units is a direct logical adaptation of the possible discrete states of the window, regarding its ventilation features

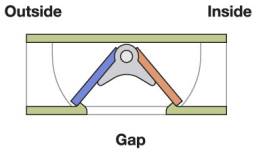
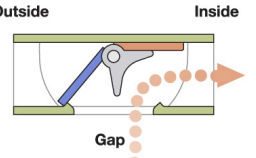
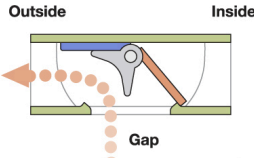
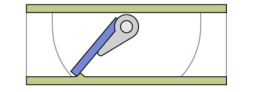
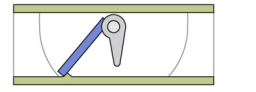
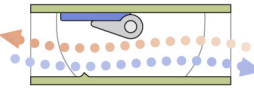
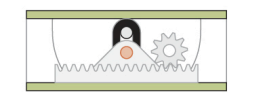
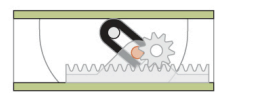
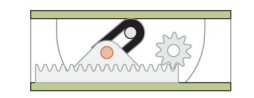
State	Closed	Pre-Heating	Self Cooling
Opening area (mm ² pr. 140mm module)	Inward: 0 Outward: 0 Bypass: 0	Inward: 1625 Outward: 0 Bypass: 0	Inward: 0 Outward: 1625 Bypass: 1625
Flap axis rotation	0°	50°	-50°
Pre-Heating/ Self Cooling module			
Bypass module			
Drive module			

Figure 7.1. Illustration of the working priciple of the ventilation modules.

Figure 7.1 illustrates the working principle of the different ventilation modules depending on the ventilation mode of the window

Closed State:

When there is no need for ventilation in the room the ventilation valves should be closed, sealing off the openings from the gap between window panes toward the outside, as well as the opening toward the inside.

In this state, the ventilation valve must provide a construction element as airtight as possible. The inherent air channels in the top frame must be shut off and insulated in the best possible way to avoid a cold bridge, that will diminish the quality of the construction, regarding its thermal insulation qualities.

Pre-Heating State:

It is determined that there is a need for ventilation in the room. Temperature sensors and the control logic determine that it is worthwhile to bring in pre-heated air through the gap between window panes. The Heating/Cooling inside flap is lifted to allow intake. At the same time the Bypass valve is kept closed.

Cooling State:

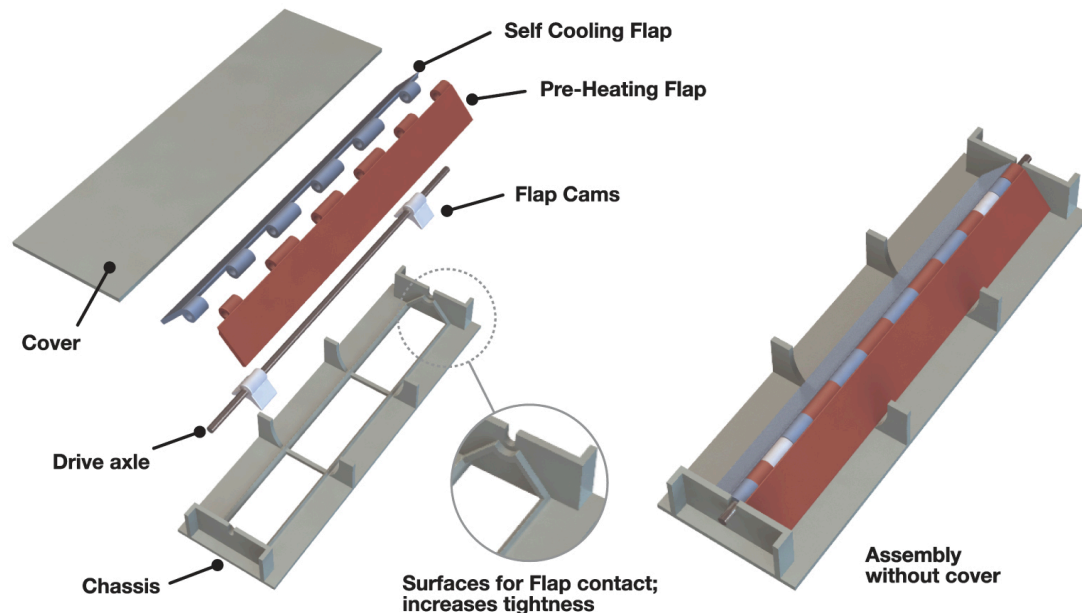
It is determined that there is a need for ventilation in the room. Control logic determines that it is not desirable to bring in pre-heated air though the gap between window panes and into the room. The Heating/Cooling outside flap is lifted to eject rising hot air in the window pane gap, thereby providing for cooling of the gap and inner pane. At the same time the Bypass valve opens to allow air to exchange freely into the room .

7.2.1 Heating/Cooling Valve description

The Heating/Cooling valve has two identical flaps, rotating around a common axis stretching centrally along the top of the unit. The flaps can move independently, lifted

by a cam fixed on the rotating axis. Only one flap is lifted at the time; if the inside flap is lifted/open, the outside flap is closed.

In the default, rest state, both flaps are held closed by means of weights attached to the upper side of the flaps. No connection between gap and outside nor gap and inside. No connection between inside and outside



When the inside flap (red) is lifted by rotation of the cam to make a connection between the windowpane gap and the inside, preheated air can be supplied to the building from the window cavity. The opening area will increase continuously from 0 cm³ to 16 cm³, when the cam rotation goes from 0 to -50 deg. (at 140 mm module width). As the cam rotates to open the inner flap, it will rotate off the outer flap that is kept closed

When the outside flap (blue) is lifted by rotation of the cam to make a connection between the windowpane gap and the outside, preheated air will be ejected from the window cavity to the outside, generating circulation with a self cooling effect. Again the opening area will increase continuously from 0 cm³ to 16 cm³, when the cam rotation goes from 0 to 50 deg. while the inside flap stays closed

Flaps are returned by steel weights attached to the upper side of the flaps.

The chassis holds the axis in place and provides contact and resting surfaces for the flaps. It has openings in three directions; a downward opening to the gap between windowpanes, an outward ward opening and an inward opening.

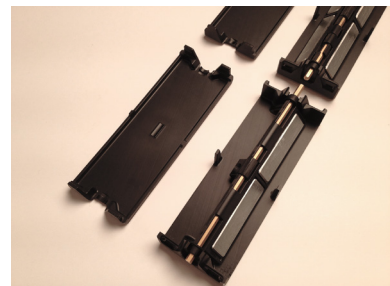
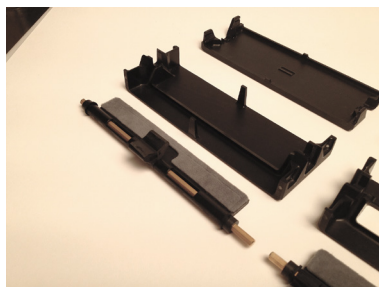
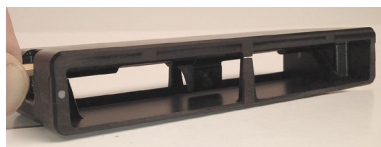
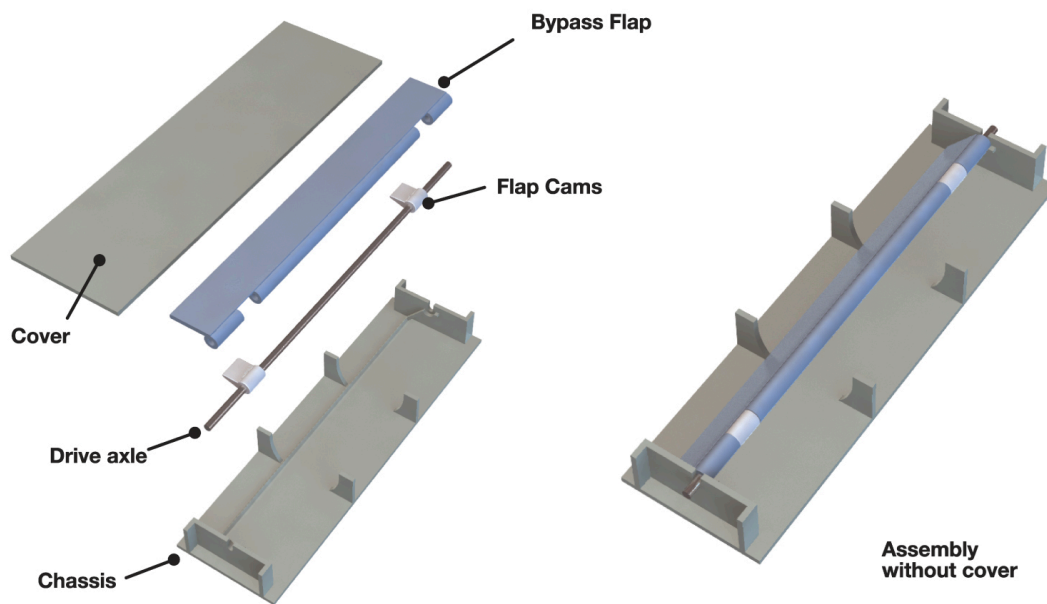
7.2.2 Bypass Valve description

The Bypass valve section is a simplified version of the Heating/Cooling section: It has only one flap to the outside, and the chassis openings connect the outside and the inside – there is no connection to the gap below. The one flap rotates freely around the same common axis, and is lifted by a fixed cam in sync with the outside flap in the heating/cooling valve, thus allowing fresh air to enter the building when the window is in the self cooling state.

It has two distinct states, corresponding to the states of the heating/cooling valve:

- (Default) Closed
No connection between inside and outside.
- Cooling State, Open:
When the window is in the cooling state, the Heating/Cooling module allows no air to flow to the inside of the room. To allow for venting of stale air and entering fresh air, the Bypass valve flap opens, rotating in sync with the Heating/Cooling outside flap.

The flap is returned by a steel weight attached to the upper side of the flap.

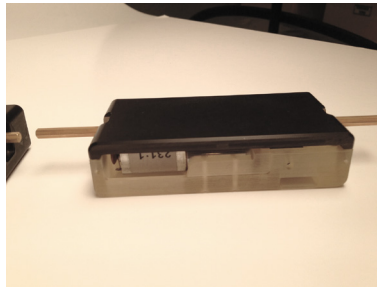
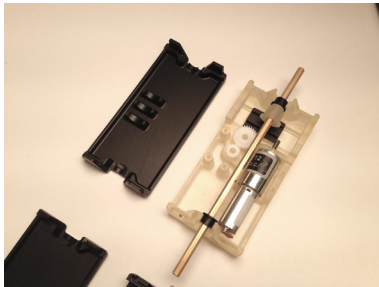
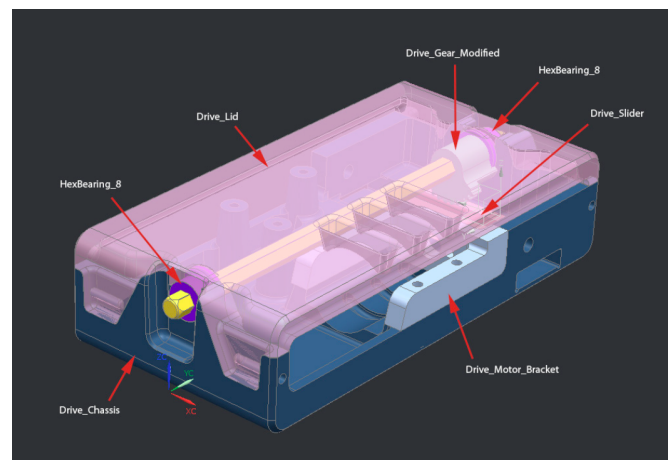
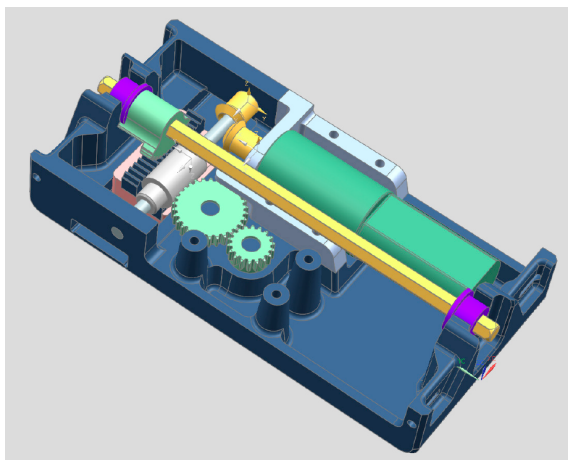


7.2.3 Drive Unit description

The ventilation valve states are changed by cams rotating on a common axis. This is accomplished by a motorized drive unit, powered by PV-panels, batteries or wired power, everything controlled by electronic circuitry.

It is based on a small DC motor with a self-locking reduction gearbox. A gear wheel on the motor spindle will drive a pin-carriage sideways, by means of a rack. The sideways motion of the pin, drives a fork attached to the drive axle through an angle of 100 deg. from end stop to end stop.

At the same time a horizontal gear wheel with a magnet attached will rotate to reflect the position of the carriage and hence the degree of drive axis rotation. The magnet orientation will be sensed by a chip on the motor driver PCB.



8. DEVELOPMENT OF CONTROL SYSTEM, DEVICES AND SOFTWARE

1 Project Goals

The UM work package is entitled “Development of Control System, Devices and Software”. Some of the project demands are written in the description of work document, while others came up during the planning meetings as well as during the development phase.

Some of the main goals can be described as following:

- Allow an easy retrofitting of existing installations;
- Use RF communications to avoid communication cables;
- Access the windows environmental data to test and to measure performance;
- Minimize the electronics dimensions to fit the window frame;
- Allow the system to operate without sunlight for two weeks;
- Control a blind’s position without feedback information;
- Control the ventilation valve;
- Select and use the sensors necessary for the thermal performance control;
- Create a communications gateway interface to allow the system integration with 3rd party devices and/or home automation solutions;

2 System Development

2.1 Overview

One of the biggest challenges of this project is to use solar energy to drive motors, perform computational tasks and perform communications.

The energy management system must be very well designed to minimize the usage of a backup recharge system. In order to achieve this goal, we need to address these main guidelines:

- Disable every part of the system that is not being currently used to save power;
- Use very low power components, such as sensors and very efficient actuators;
- Use an energy efficient communication technology;

The hardest part to accomplish in the Climawin project was the communication technology and the algorithms around it to use as less energy as possible without compromise the communication range and efficiency.

The RF communications available nowadays for this kind of application can go from very simple radio transceiver, that sends and receives binary data, to very complex radio links, with several layers of the OSI model implemented that will provide a much better data integrity, speed, tolerance to failure and noise immunity.

The radio transceiver must be capable of bidirectional communications. The transmitter is only used sporadically, when sending data and since the data is only a few bytes wide and the speed of these networks is usually around several the Kbps, the transmitter will use a few milliamps during just a few microseconds. This is a very easy thing to accomplish.

The main technological challenge is related to the reception of data, because in order to receive messages, the transceiver must have the receiver listening for radio activity all the time, thus consuming energy all the time.

Looking at the power consumption of low power radio receivers we have the following options available at the market (for our application type):

1. Complex radio receivers with good sensitivity: 35mA-45mA;
2. Very basic radio receivers with poor sensitivity: 10mA-30mA;

Besides the current consumption, there are other important parameters worth of a close analysis, like the modulation type, maximum transmission distance, error detection mechanism, collision handling mechanism, spectrum “pollution” and usage of available bandwidth.

The EnOcean receiver has a lot of good characteristics, from good transmission speed, good transmission distances, low power transmission and low spectrum “pollution”, but the spent receiver energy is too much to be driven by batteries all the time. However, EnOcean has a good solution to overcome this handicap: the Smart-Ack technology.

The Application Note 501 from EnOcean explains this technology in details.

This technology basically requires a wall-powered device somewhere within the radio range of the device, to hold the data that is to be sent to the battery driven device, pretty much like a very basic mailbox server.

This is the core technology involved in the Climawin electronics development.

2.2 *EnOcean Equipment Profiles*

2.2.1 Climawin Profile

The EnOcean standard defines a set of messages for different applications, from temperature sensors, humidity sensors, light sensors, time “server”, rocker switches, CO2 sensors, door handlers, etc. All these message structures are documented and every device with the same characteristics MUST use the same message structure, so that similar devices from different vendors are interchangeable.

Since there is no device with similar characteristics as the Climawin windows, we need to establish our own protocol, trying to make it as close as possible to the policy defined by the EnOcean Alliance. Before the first meeting in Bamberg UM went to the EnOcean headquarters near Munich and had a meeting with Mr. Norbert Metzner that advised to follow some guidelines in order to make the Climawin profile a standard, after the product gets to the market.

The profile information from the Climawin window is composed by a telegram with learn information, like manufacturer code, device type, etc, and several telegrams that the window will send and receive with information about sensors, blinds, buttons, and actuation requests.

The learn procedure is well explained in the EnOcean Equipment Profiles EEP2.1 [1] as well as the telegram structure for the several devices, including the CO2 EnOcean sensor.

The Climawin window teach-in telegram and the data telegrams are explained next.

2.2.1.1 Teach-In telegram

The principle of operation of a teach-in procedure for a smart-ack application is presented in the Figure 1.

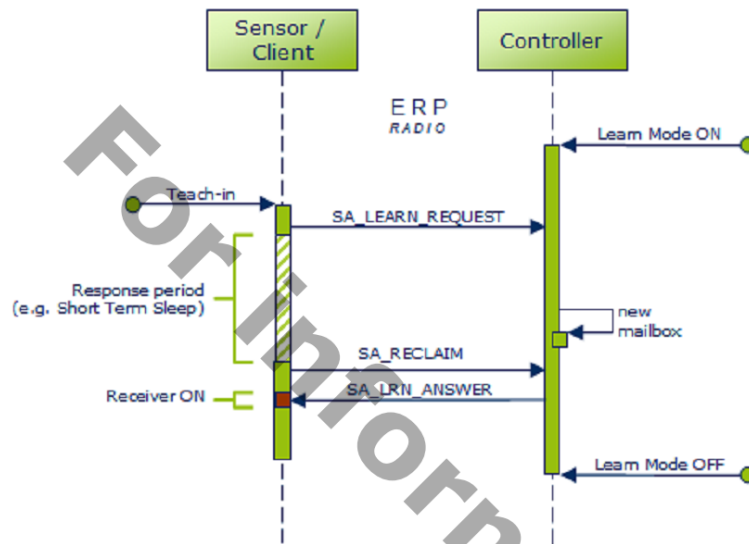


Figure 1 - Teach-In procedure scheme for smart-ack [1]

The teach-in telegram structure is composed by 4 bytes, using the following scheme:

Smart Ack Learn Request

RORG	Req	Manuf. ID	EEP (3 byte)			RSSI	Repeater ID				Sender ID				Status	CHKS
0xC6	5 bit	11 bit	EEP3	EEP2	EEP1	dBm	ID_3	ID_2	ID_1	ID_0	ID_3	ID_2	ID_1	ID_0	1 Byte	1 Byte

We will define the following data for the window:

- **MANUFACTURERID = 200**
- **EEP1 (RORG) = 0xD2**
- **EEP2 (FUNC) = 0x55**
- **EEP3 (TYPE) = 0x00**

The remaining data to load is the following:

Data	Value	Description
Request code	0b11111	Default value – send by sensor
Manufacturer ID	0bnnnnnnnnnnnn	Corresponding to the teach-in sensor (200)
EEP No.	0xD2 0x55 0x00	RORG, FUNC, TYPE
RSSI	0x00	0 = Without repeater
Repeater ID	0x00000000	0 = Without repeater
Sender ID	0xnnnnnnnnnn	Chip ID of sensor for teach-in

Status	0x0F	0F = no repeating permitted
CHKS	0xnn	Checksum calculated

2.2.1.2 Sensor Data Telegram

The sensor data telegram is the message that carries the information about the blind position, blind rotation angle and the current valve angle.

This message is dispatched every time there is a change in the blind or valve position, either caused by the control algorithm or by the user interaction.

The message structure based on a 4BS telegram structure (see [1] for more information), in which the first data byte determines the message type, and the remaining bytes carry that message data. The data types can be the following:

ACTUATOR_STATE = 128

AUTOMATIC_BEHAVIOR = 129

The ACTUATOR_STATE message carries the information about the blind vertical position, the blind flaps rotation and the current valve angle. The message structure is detailed in the following table:

Offset	Size	Bitrange	Data	Shortcut	Description	Valid Range	Scale	Unit
0	8	DB3.7..DB3.0	128	MSG_TYPE	ACTUATOR_TYPE	Enum: 128: ACTUATOR STATE 129: AUTOMATIC BEHAVIOR		
8	8	DB2.7..DB2.0	BLIND POSITION	BLIND_POS	Blind vertical position	0..100	0%..100%	%
16	8	DB1.7..DB1.0	BLIND ROTATION	BLIND_ROTATION	Blind flaps rotation	0..100	0%..100%	%
24	4	DB0.7..DB0.4	VALVE POSITION	VALVE_ANGLE	Valve angle	0..100	0%..100%	%
28	1	DB0.3	LRN bit	LRN bit	Learn bit	Enum: 0: Teach-in telegram 1: Data telegram		
29	3	DB0.2..DB0.0	VALVE POSITION	VALVE_ANGLE	Valve angle	0..100	0%..100%	%

This message is sent by the window controller every time some of this situation is changed and can also be sent by the home automation to set the blind and valve to a desired position. The content and structure of the message is exactly the same, filled with the desired values. The window controller after interpreting the message will move the motors to achieve that goal.

The AUTOMATIC_BEHAVIOR message indicates if the window automatic behavior has been overridden for maintenance or not.

The AUTOMATIC_BEHAVIOR message structure is the following:

Offset	Size	Bitrange	Data	Shortcut	Description	Valid Range	Scale	Unit
0	8	DB3.7..DB3.0	129	MSG_TYPE	ACTUATOR_TYPE	Enum: 128: ACTUATOR STATE 129: AUTOMATIC BEHAVIOR		
8	8	DB2.7..DB2.0	n.a.	n.a.	Not used	n.a.		
16	8	DB1.7..DB1.0	OVERRIDE	OVERRIDE_STATE	Indicates if the override is active or not	Enum: 1: Override active 0: Override inactive		
24	4		n.a.	n.a.	n.a.	n.a.		
28	1	DB0.3	LRN bit	LRN bit	Learn bit	Enum: 0: Teach-in telegram 1: Data telegram		
29	3	DB0.2..DB0.0	n.a.	n.a.	Not used	n.a.		

2.3 Zone Controller

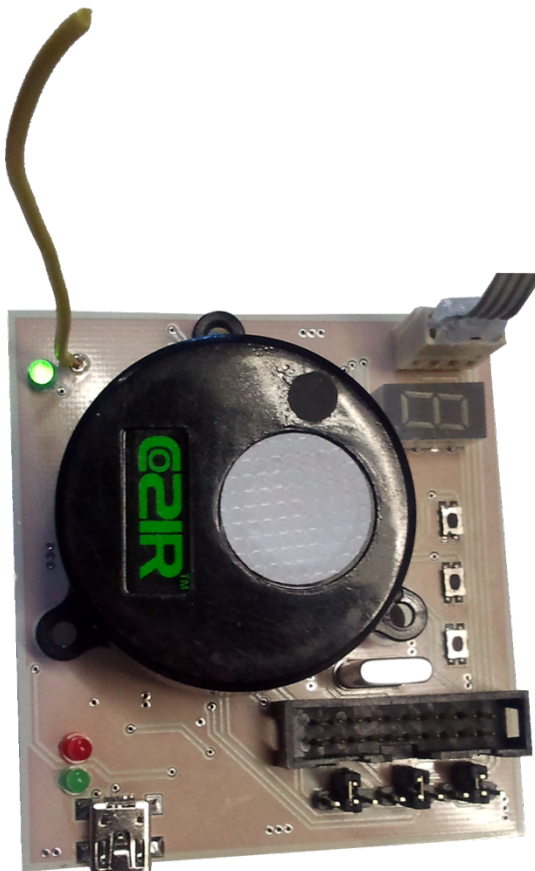


Figure 2 - Zone Controller prototype

2.3.1 What its purpose?

The zone controller is the device responsible for handling and storing data to send to the window controller device, while its radio transceiver is disabled to save power. The zone controller will then send the held data to the window controller, whenever the window controller wakes up and asks for any possible data that was sent to him in the meanwhile.

The zone controller allows the window to operate with less energy than it would operate if the system didn't have the ability to hold data in the zone controller.

The zone controller also has the possibility to get CO₂ data if the COZIR sensor is attached to the PCB. This is good for simple installations, where the customer only needs to get the CO₂ value of a single place to control one or more windows. Other 3rd party CO₂ sensors can be integrated in the system to get the CO₂ from different zones and apply them to different windows. This configuration must be done according to the learning mechanisms developed, described in the Chapter 0.

2.3.2 How many devices can it handle?

The zone controller will store the devices information for which he is responsible in its own memory system. It also needs to reply to the window controllers in a small time frame to make sure the window gets the message in the short period from which he listening for messages.

For such reasons, the zone controller resources are limited, both in terms of memory and reply time.

Every window may have a rocker switch associated as well as a CO₂ sensor.

In order to get a better "memory arrangement" compromise between windows, rocker switches and CO₂ sensors, we created the notion of zone.

A zone is therefore defined as a limited group of windows, that can be simultaneously operated with a single rocker and that will all receive the CO₂ value from a single sensor. This may be a common situation for a living room or even a kitchen.

The memory arrangement created has the following rules:

- Every zone may have up to 3 windows;
- Every zone may have a CO₂ sensor attached;
- Every zone may have a single rocker attached;
- A rocker switch may be attached to more than one zone;
- A CO₂ sensor may be attached to more than one zone;
- Each zone controller may control up to 5 zones;

These rules also allow some flexibility to extend what may appear to be limitations. To explain this statement lets imagine the following situation:

We have a living room with 5 windows, and the customer wants to move the five windows with a single remote switch and get the CO₂ parameter from a single sensor. The zone controller can be programmed as such:

1. Associate 3 windows to the zone #1;
 2. Associate the rocker switch to the zone #1;
 3. Associate the CO₂ sensor to the zone #1;
 4. Associate the remaining 2 windows to zone #2;
 5. Associate the same rocker switch to the zone #2;
-

6. Associate the same CO2 sensor to the zone #2;

As a result, we used two zones and the switch will be used to operate both zone #1 and zone #2, and the CO2 sensor is also coupled to both zones.

2.3.3 What if the radio signal is not strong enough?

There will be situations where the radio signal may not be strong enough to establish a reliable communication between the zone controller and the window. The zone controller placement is crucial to get the best from the building characteristics.

The EnOcean EPM 300 is a mobile field intensity meter developed to get the radio signal intensity in a specific place, allowing the installer to determine the ideal mounting position for the zone controller and from the rocker switches (if these are to be fixed to a wall).

It can also be used to detect faulty connections on devices already installed.

The *EnOcean Application note 001 - EnOcean Wireless Systems – RANGE PLANNING GUIDE*, available for download at the EnOcean website is a very good manual with the best installation procedures methods.



Figure 3 - EPM300 field intensity meter

If the radio link is weak or not enough, a repeater may be used to cover a wider extension and overcome possible obstacles that would be impossible otherwise.

These are standard devices available on the market, but it must be capable of using the Smart-Ack technology, since this is the core technology used to develop the system and the old repeater models may not support it.

2.3.4 The zone controller CO2

The zone controller has a COZIR® CO2 sensor circuit built-in and whenever a sensor is attached, it will make the measurements and send the value to the target windows. It will also send the data as a broadcast message to the monitoring/home automation system.

The zone controller may be used without the CO2 sensor attached, both for situations that don't require it, and for situations where a 3rd party sensor will be used to get a more accurate reading, since those 3rd party sensors can be wireless and battery less.

The Figure 4 is the circuit schematic that handles the COZIR sensor interface.

The COZIR sensor communications interface is RS232 based, but since the zone controller's only RS232 port is reserved for the USB to PC interface, the SC16IS740 chip was used to convert the RS232 protocol into I2C and thus, use the microcontroller GPIO pins to get the desired data.

The MAX1595 step-up converter was used to convert the system 3V to 5V, since this is the COZIR sensor nominal voltage.

The WXIDIO pin is used to enable/disable the sensor by a digital switch based on a N-MOS and a P-MOS mosfet configuration.

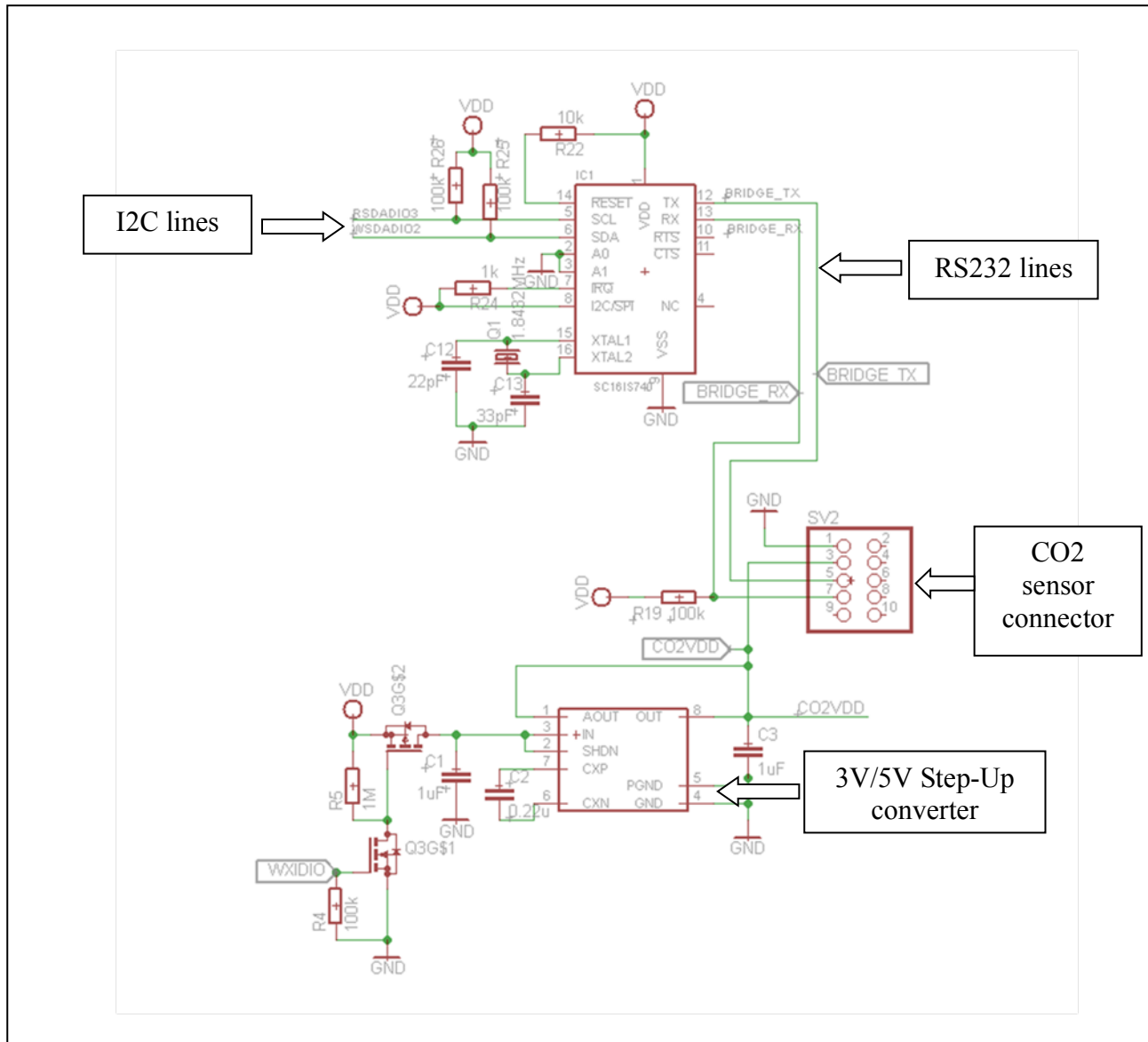


Figure 4 - CO2 sensor interface circuitry

2.3.5 The CO2 sensor auto-calibration feature

COZIR sensors are fully calibrated prior from the factory. Over time, the zero point of the sensor needs to be calibrated to maintain the long term stability of the sensor.

In many applications, this can happen automatically using a simple software technique. This technique can be used in situations in which sensors will be exposed to typical background levels (400-450ppm) at least once during the auto-calibration period. For example, many buildings will drop quickly to background CO₂ levels when unoccupied overnight or at weekends. The auto-calibration function uses the information gathered at these periods to recalibrate.

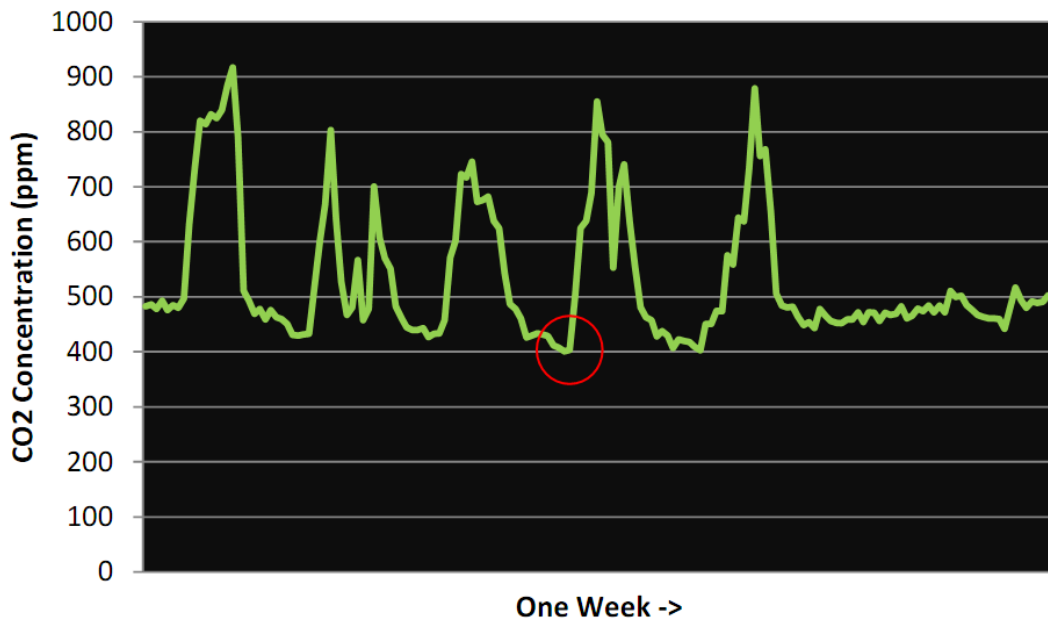


Figure 5 - CO₂ values over a week, showing a background value for calibration.

This recording from a sensor shows a typical one week recording in an office environment. The auto-calibration function uses the low point (circled) and uses it to recalibrate the zero point. The auto-calibration feature has been added to the system after the Fraunhofer tests, where one sensor got de-calibrated after the window was moved from Stuttgart to Holzkirchen.

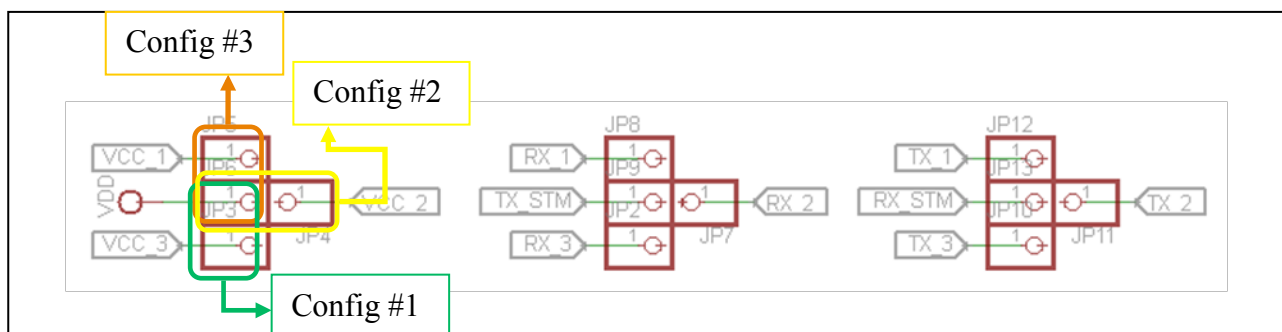
2.3.6 The zone controller communication interfaces

The microcontroller device has a single RS232 port that can be used for:

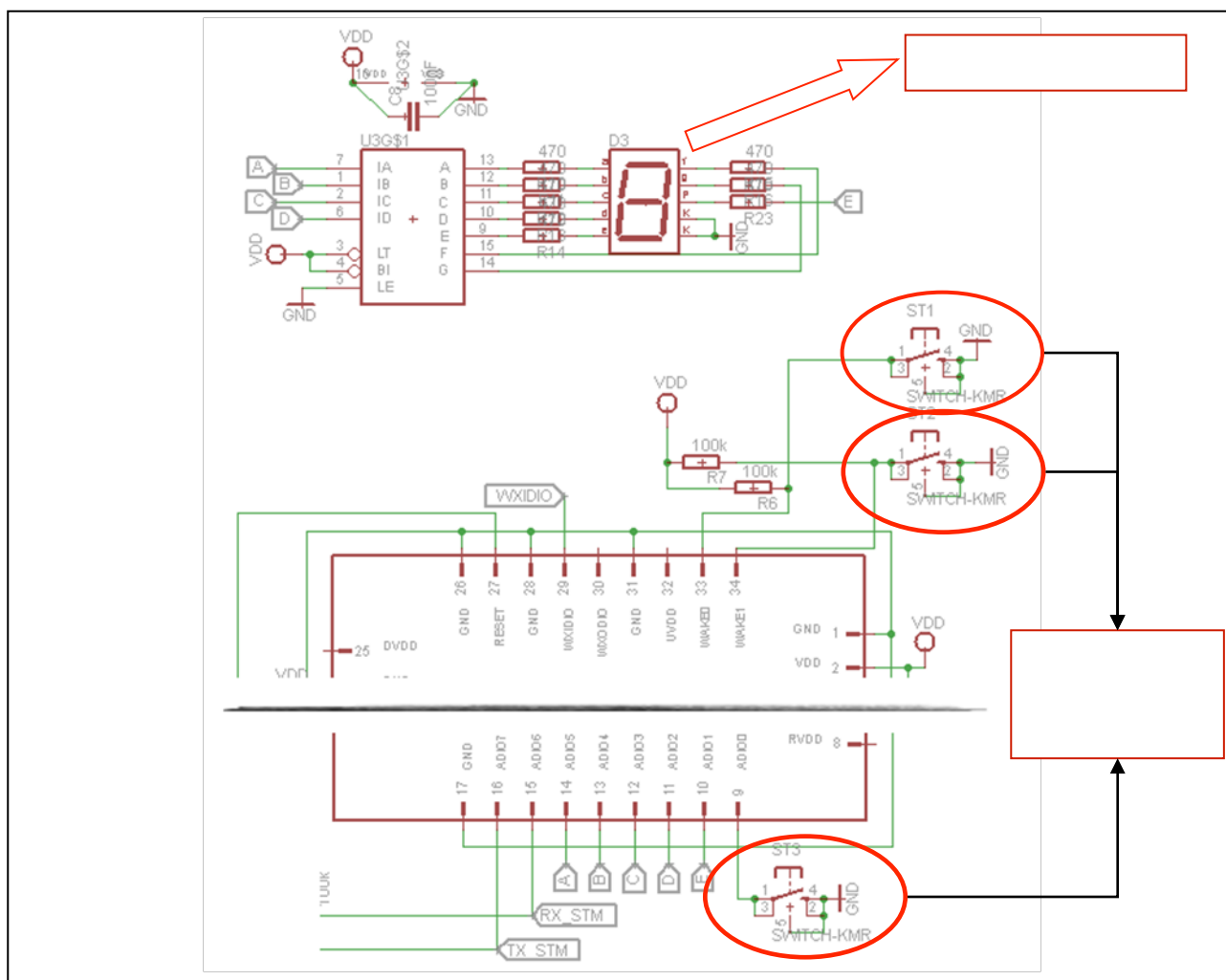
1. USB interface to the PC or router;
2. Microcontroller programming and debugging;
3. RS232 interface to the NGW100 development board or equivalent system;

The first situation is the 'deployment' configuration mode, but in order to use the development programmer, one must configure the PCB for the configuration 2. The third option is not common, as it is only necessary if the system uses the NGW100 or if it is necessary to get a TTL RS232 interface available.

The configuration system is based on jumper switches, and the mechanical disposition of the pins does assures that no short-circuit can be created using jumpers. The Figure 6 shows the schematic circuitry for the power supply and RS232 channels selection. As one can see in the first switch scheme, there are 3 ways to connect the jumper to configure the system for the configuration #1, #2 or #3.



The zone controller has a built-in interface to configure the windows, rocker switches and the local or remote CO2 sensors in a user-defined, specific configuration. To do this, there is a 7-segments display and 3 buttons.



2.3.8 The zone controller firmware

The zone controller firmware is basically based on an infinite loop with the following main procedures represented in the following scheme:

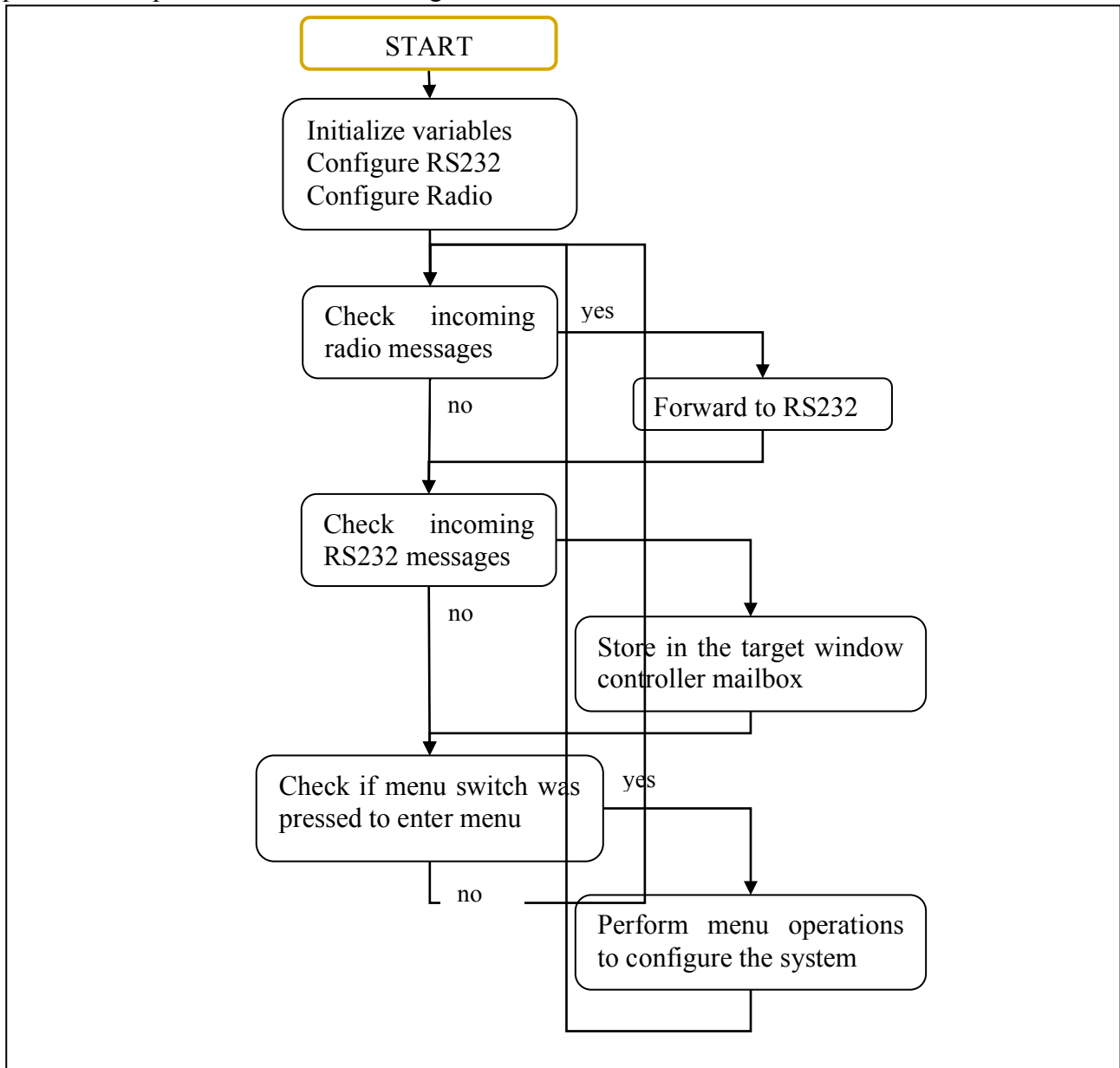


Figure 8 - Zone controller firmware main blocks

All the loop blocks are non-blocking to keep the information flowing in both directions.

2.4 Window Controller

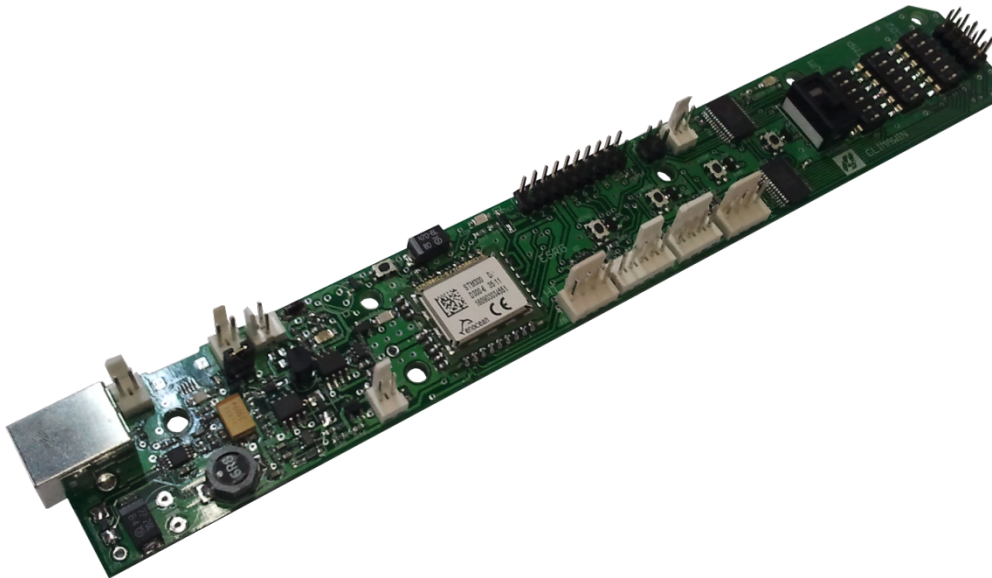


Figure 9 - window controller PCB

2.4.1 What its purpose?

The window controller is the device responsible for handling the valve, the blind and for receiving the user demands to change the blind and valve state. It has a set of algorithms to decide the best valve and blind positions and create that state without user interaction.

It has a RF transceiver module to send and receive data and a battery management system, with a backup charging scheme and solar power charger to create a very efficient autonomous system.

The main board has a set of connectors to plug in sensors, a solar panel, a battery, a USB connector for backup recharging and a motor controller PCB to handle the power conversions and overcurrent protection mechanisms.

2.4.2 Interface with user: Buttons

The PCB has a set of buttons to fulfill the user interaction requirements, defined during the project development:

1. Move blind up;
2. Move blind down;
3. Set valve to cooling mode;
4. Set valve to heating mode;

There is also an isolated button to configure the device

5. A learn button

The first group of buttons (1-4), shown in detail in Figure 10 is connected to the digital expander because the microcontroller has not enough pins for all the system requirements.

The 4 buttons are connected to both the WAKE0 pin of the microcontroller in an OR scheme, using just diodes and to the digital expander. This is necessary because the user may press the button

during the sleep period and in that case, the microcontroller will detect through the WAKE0 pin, and request an expander reading immediately, to identify which button was pressed.

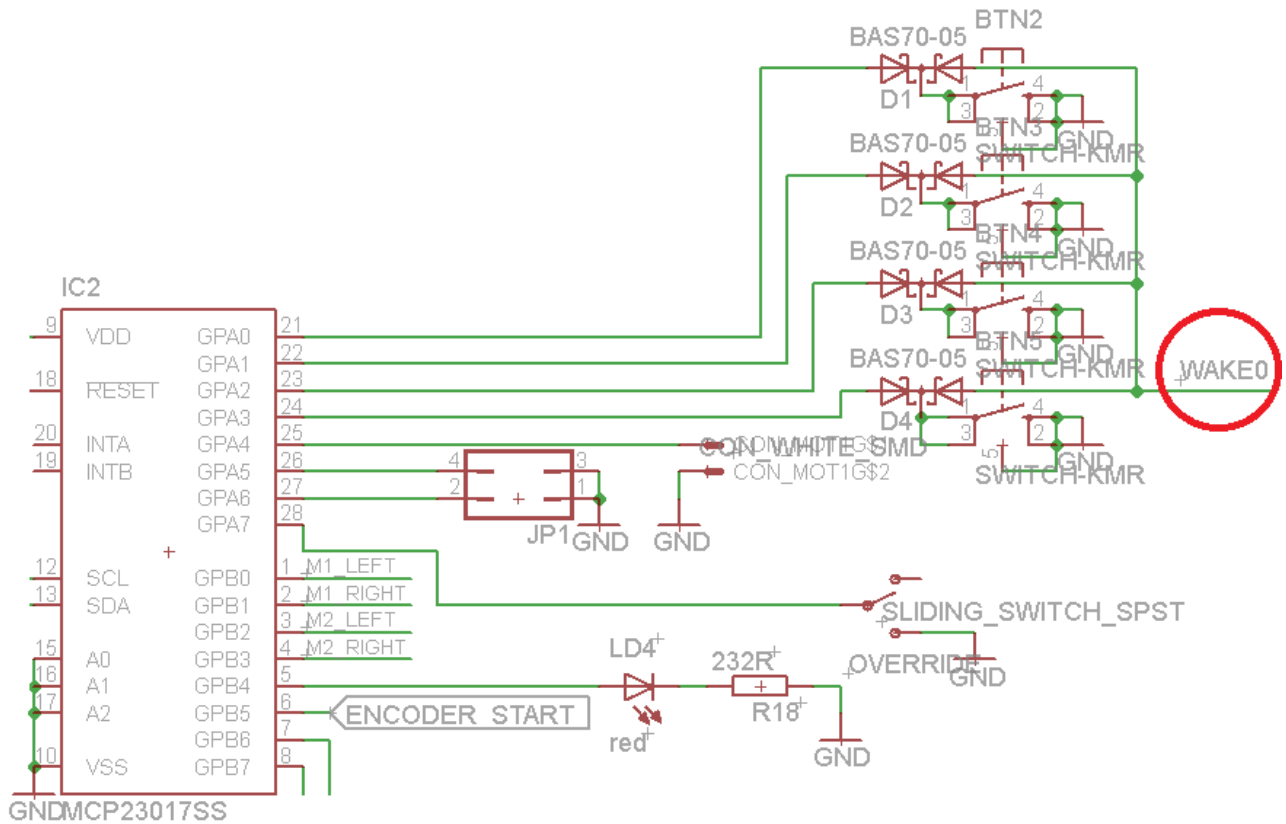


Figure 10 - Buttons connected to the expander detailed circuit

The learn button is also connected to the microcontroller WAKE0. It is not necessary to connect this button to the expander because if the microcontroller detects no button pressed by the expander interface, it will assume that the learn button was pressed.

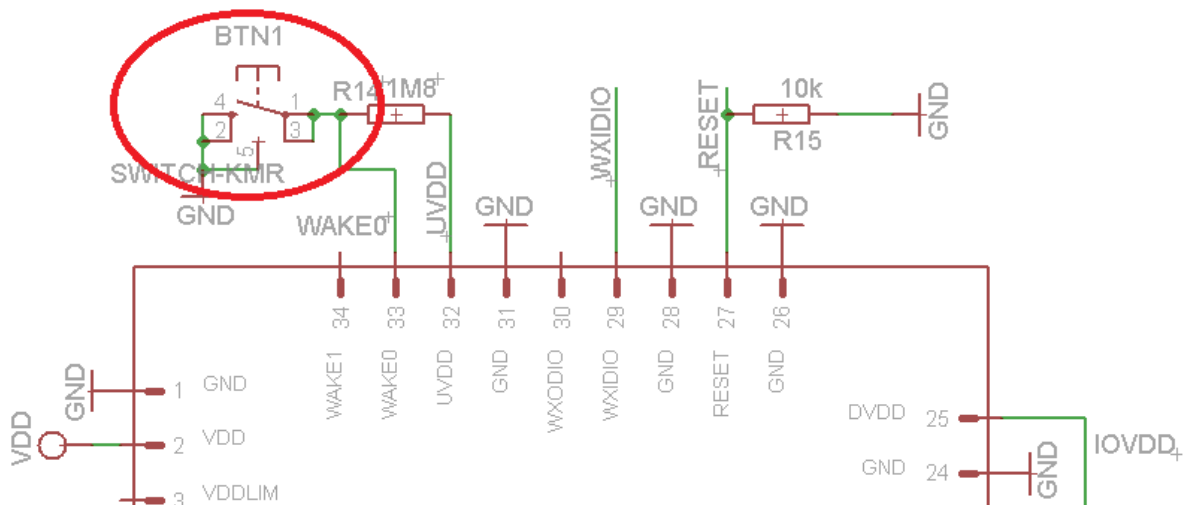


Figure 11 - Learn button circuit

2.4.3 Interface with the User: Leds

The window controller has a set of leds to signal the following situations:

1. Processor active;
2. USB power existent;
3. Battery charging;
4. Battery charge complete;

The following picture shows the led positioning and their meaning in the window controller PCB.

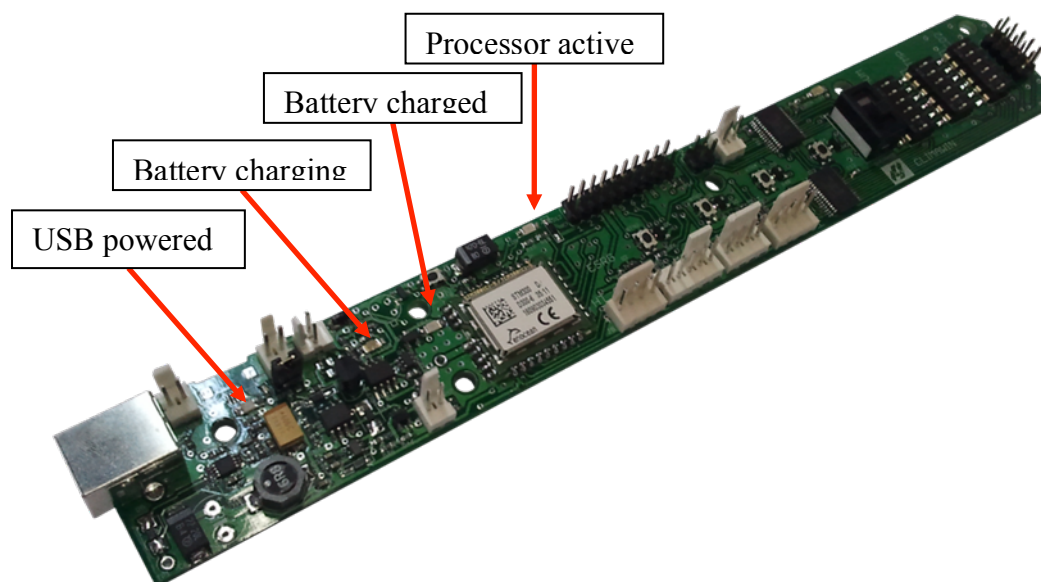


Figure 12 - Leds placement in the window controller PCB

2.4.4 Override automatic operation

The window has 3 sources of override with different priorities:

1. Software lock override:
This type of override is set by home automation software to take full control of the window automatic behavior, and use its own algorithms. This is the highest priority source of override;
2. Sliding switch override:
This type of override can be set using the sliding switch existent in the window controller PCB. This feature is important to keep the window from moving itself automatically, whenever the user finds it necessary, for instance, during the window transportation or during maintenance routines;

3. Temporary override: Every time the user requests for some action, either a blind or valve movement, the system will ignore the automatic algorithm for the next 30 minutes (defined in the constant: `TEMPORARY_OVERRIDE_PERIODE_MS`); This is the lowest priority override;

2.4.5 Blind types

The original blinds accepted as model as basis for the product development was a Warema motor E. This blind operates with a 24V DC motor that stops mechanically at the lower and upper positions, thus enabling the controller to re-calibrate in these two situations. After the testing propotype has been developed, RAUH presented a new kind of Warema blind, the G motor, that doesn't stop at the lowest point, instead, the blind starts moving upwards and finally gets mechanically stuck in the top, if the motor is actuated for long enough.

This new type of blinds is virtually impossible to control without feedback, while assuring that the blind will never get stuck. The blind position is measured based on the actuation time, and the position is only calibrated when the blind reaches the limits. Since the G Motor doesn't stop at the bottom, there is no calibration point there, and the perceived blind position will get more and more inaccurate, making it possible to get stuck after some actuations.

2.4.6 Control algorithm

The control algorithm was developed by Aalborg University and implemented in the window controller. The algorithm is used to move both the valve and the blind, but since the motor presented to perform the tests was the G Motor, and there was no way to make sure that the blind wouldn't get stuck, we agreed to use the control algorithm to move only the valve, while the blind was operated manually using the rocker switch.

The control algorithm is implemented as the `smartValveControl` function, in the `ControlAlgorithm.c` file, from the window controller project.

2.4.7 Configuration switches

The window controller has a set of switches to configure some parameters to apply in the automatic control algorithm, such as the temperature, humidity and CO2 limits.

The switches position and configuration details are presented in Figure 13.

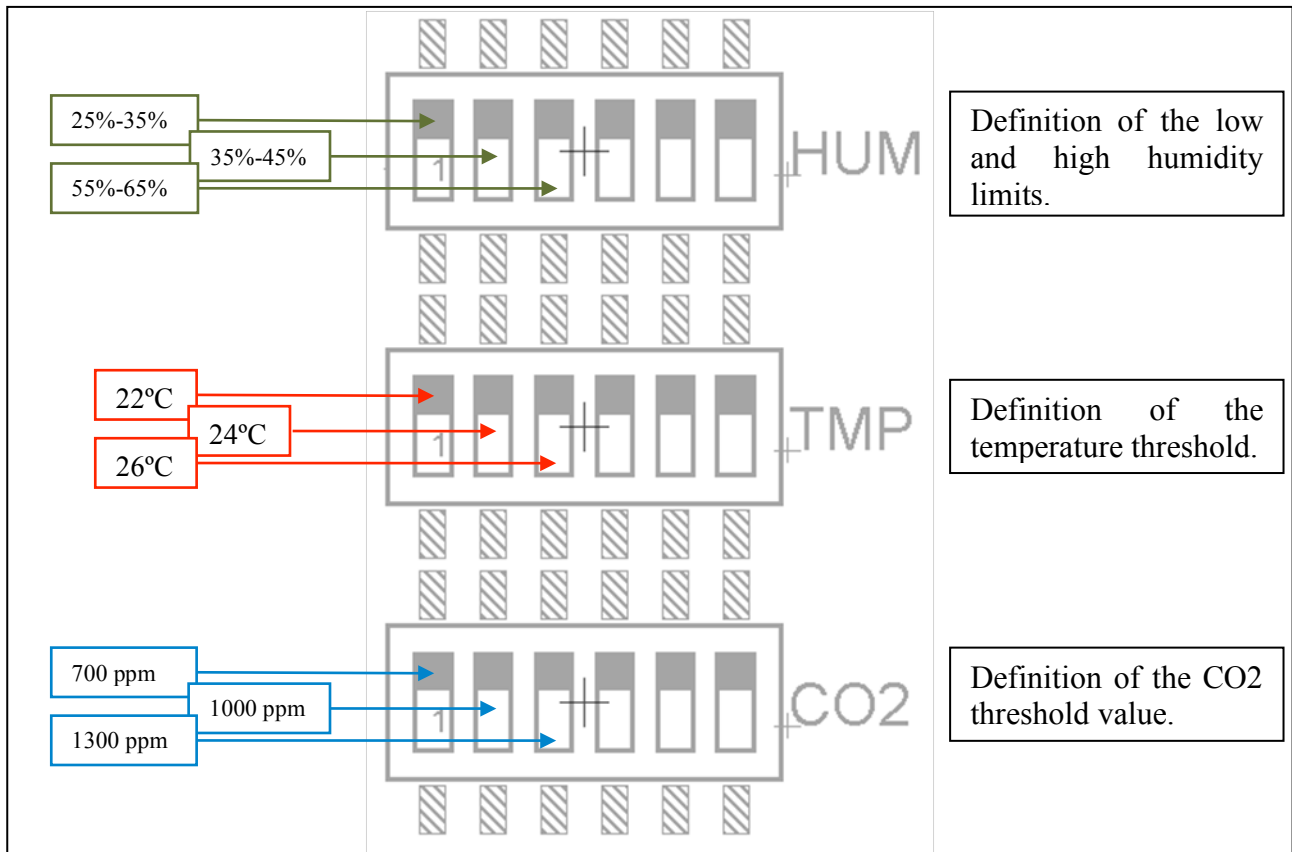


Figure 13 - Control algorithm threshold values configuration

When the switch is up, the corresponded value is selected. If more than one switch is up, the lowest value is selected. If no switch is up, then the smallest value is used as default.

2.4.8 Learn Button

The learn button is used to perform the association between the window and one or more zones inside the zone controller configuration scheme.

When the user pressed this button, the window controller wakes up and sends a learn request that will be listened by all zone controllers in that area and reply to the ones that are in configuration mode.

2.4.9 Battery and Battery charger

The battery capacity was calculated to withstand all the required energy, performing 10 valve operations a day and two complete blind maneuvers per day, for two weeks without harvesting any energy (without sun).

The Saft VHT series, with 4-cells, 2000mAh, Ni-Mh chemistry, was selected due to the performance characteristics, long life expectations and peak current capacity.

The chemistry is also important for commercialization, because the European laws are very strict when using Lithium or Ni-Cd, due to environmental and safety reasons.

The first battery charger designed was a fast charger, with charge 3-cells only, but the charger had to be re-designed to a standard/trickle charger when the battery was changed to 4-cells, because a standard USB port doesn't have enough power to fast charge such batteries.

A USB type B connector can be soldered into the PCB itself or a small add-on can be used to bring the USB connector to outside the window frame.

The PICX shows the add-on and the

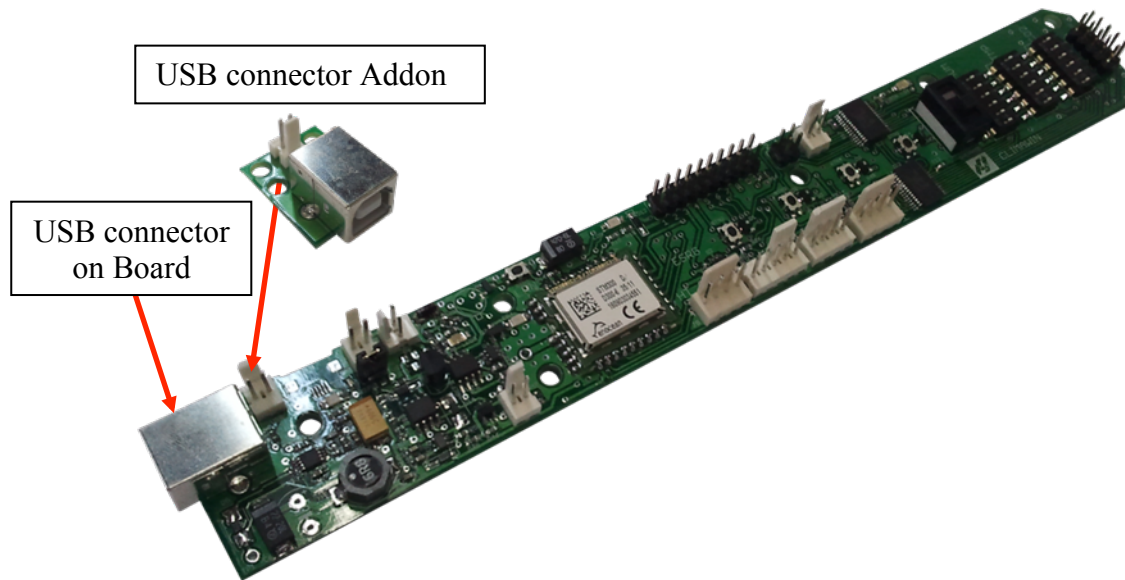


Figure 14 - Window controller with On-Board USB connector and the add-on alternative.

The battery charger is as stated, a standard charger/trickle charger controlled by the microcontroller. It is based on the LM2621 boost converter working as a switching current source. The LM2621 circuit and configurations are presented in the manufacturer datasheet as basic examples. We changed the feedback loop to use it as a current source instead of a voltage source.

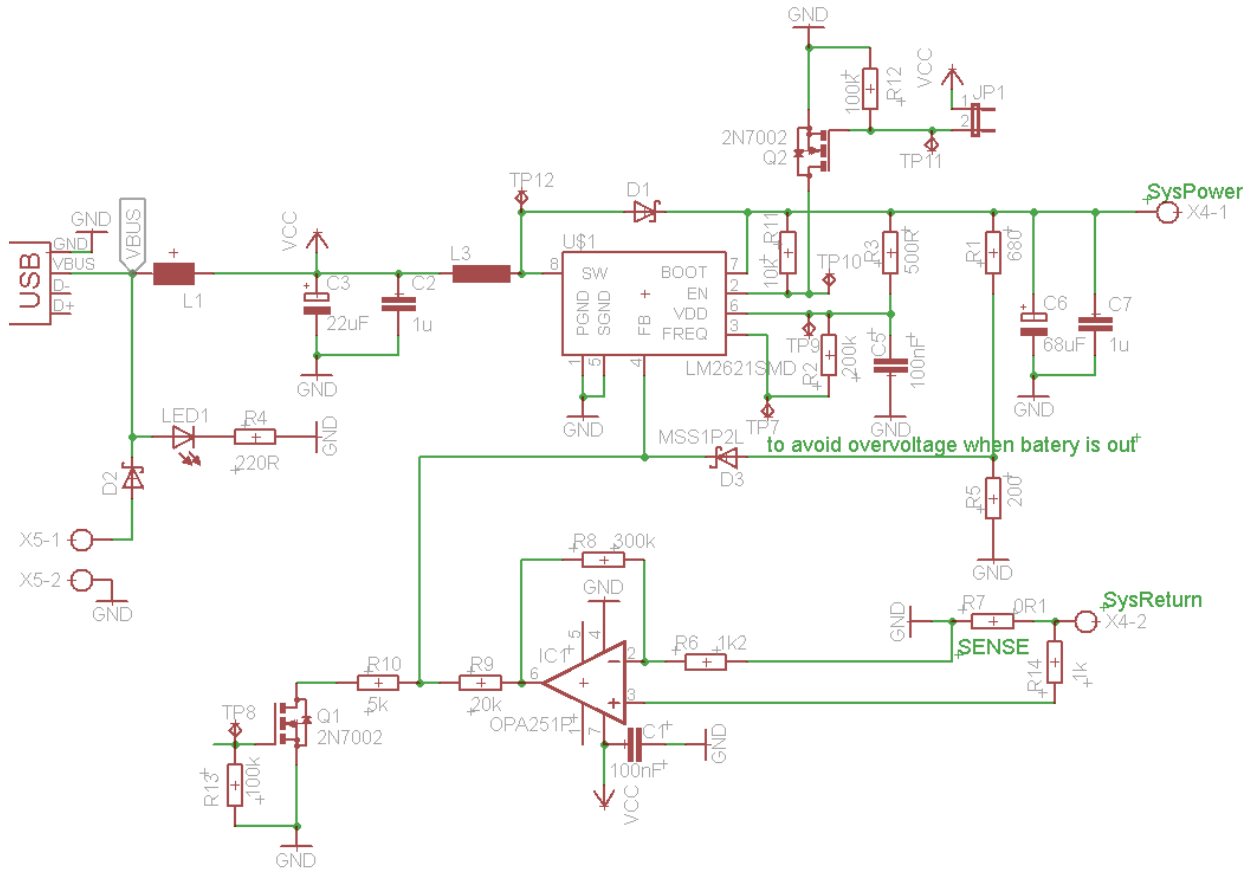


Figure 15 - Battery charger test circuit

The circuit uses a shunt resistor to sense the charging current. Then the OPA251 low-offset operational amplifier is used to provide the correct feedback signal to the boost converter.

R1 and R5 (Figure 15 **Error! Reference source not found.**) are used to avoid an overvoltage at the output of the circuit when the battery is removed. Otherwise, this would cause damage to the load.

According to the battery manufacturer specifications, we should use a $C/10$ current to standard charge the batteries, and then change to a trickle charge state using a charge current from $C/100$ to $C/20$.

Since the batteries capacity is defined as 2000mAh, we decided to use a standard charge current of 200mA and trickle charge current with $C/40 = 50\text{mA}$.

From the manufacturer data, the trickle charge goes from $C/100$ to $C/20$.

The OPA251 is configured as a non-inverting amplifier.

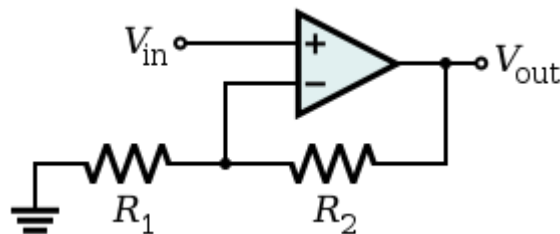


Figure 16 - Non-inverting amplifier (image from wikipedia)

The feedback threshold voltage of the boost converter is 1.23V, so this is the voltage that the OpAmp should produce when the sense current is 50mA.

We will use a voltage divider to divide the voltage on the boost feedback pin, controlled by the microcontroller to get an output current 4 times bigger (200mA).
To get a current of 50mA we need to get $V_{out} = 1.23V$.

$$V_{out} = V_{in} * \left(1 + \frac{R_2}{R_1}\right)$$

Using a 0.1 ohm resistor as the current sensor we will get a voltage across the sensor of:

$$V_{sense} = 0.05 * 0.1$$

$$V_{sense} = 5mV$$

Setting $R_2 = 300k$, we get:

$$V_{out} = V_{in} * \left(1 + \frac{R_2}{R_1}\right)$$

$$1.23 = 0.005 * \left(1 + \frac{300k}{R_1}\right)$$

$$R_1 = \frac{300k}{245} = 1224 \text{ Ohm}$$

The Q1 mosfet along with R9 and R10 (Figure 15) will allow the microcontroller to change the charge current up to 4 times more (200mA). This value can be changed in the future but pay attention that the current in the USB should not exceed 500mA, as this is the maximum current allowed by most USB chargers.

Adjustments:

Using a potentiometer to adjust the R1, we get $R_1 = 2.6k$ for a 50mA output. While $R_2 = 300k$.

At the output of the Ampop we will use a voltage divider enabled by a mosfet to allow a bigger charging current (Figure 17). A Potentiometer in R10 was used to get the exact resistor value that will charge the batteries with 150mA. This is the current at the output of the boost converter that will request 500mA from the USB supply.

Using $R_9 = 200k$, we get $R_{10} = 120k$.

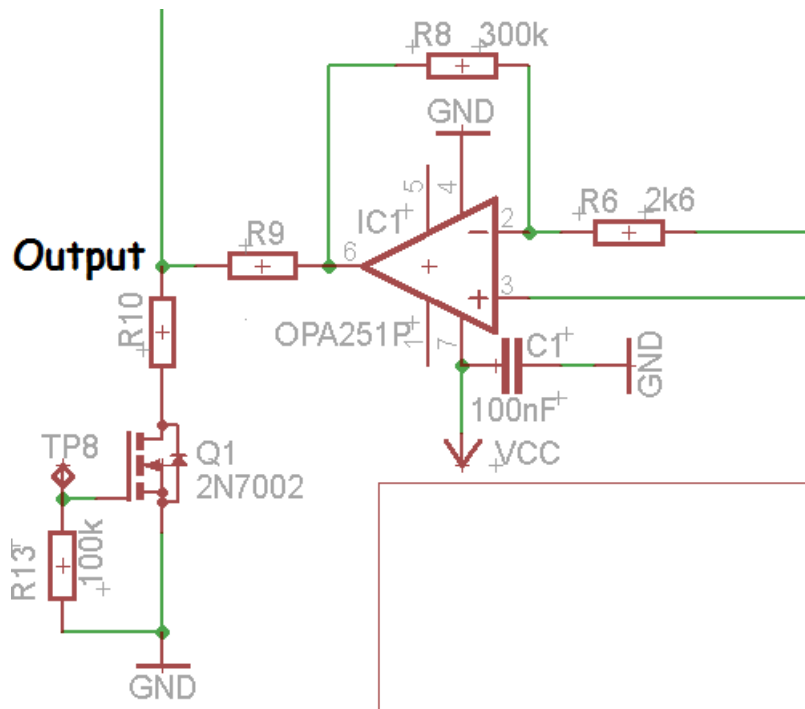


Figure 17 - Voltage divider to allow a faster current

2.4.10 Solar panels

We will want to recharge the selected battery in a limited amount of time, with an average light intensity established in advance and considering that no energy is spent in the process.

The solar panel presented in Figure 18 is a small monocrystalline solar panel used in the prototype.

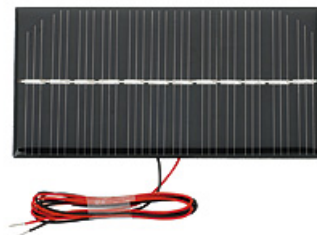


Figure 18 - Solar panel used for prototype assessment

The characteristics of this solar panel are the following (manufacturer specifications):

- Power Output: ~6V @ 1W (~167 mA)
- Output Type: DC Voltage
- Dimensions: 4.9 x 2.5 x 0.13 in (125 x 63 x 3.4 mm)
- Operating temp range: +32 to +158°F (0 to +70°C)
- 0.167 I_{pm} (A) Max Operating Current
- 7.2 V Open circuit Voltage
- 0.183 I_{sc} (A) Short Circuit Current
- Price: \$12

We installed 3 of these in parallel to the RAUH window used for demonstration. The battery energy recharge level was very good, but the system will work fine with just two solar panels.

The Figure 19 shows the battery level log for more than a month during the tests at Holzirchen. The capacity level was high all the time, which means that the 3-solar panels in parallel are enough for this climate, using this orientation, during the measured month and for this level of usage. The final measurements don't apply because there was a short-circuit caused by a human error during a maintenance operation.

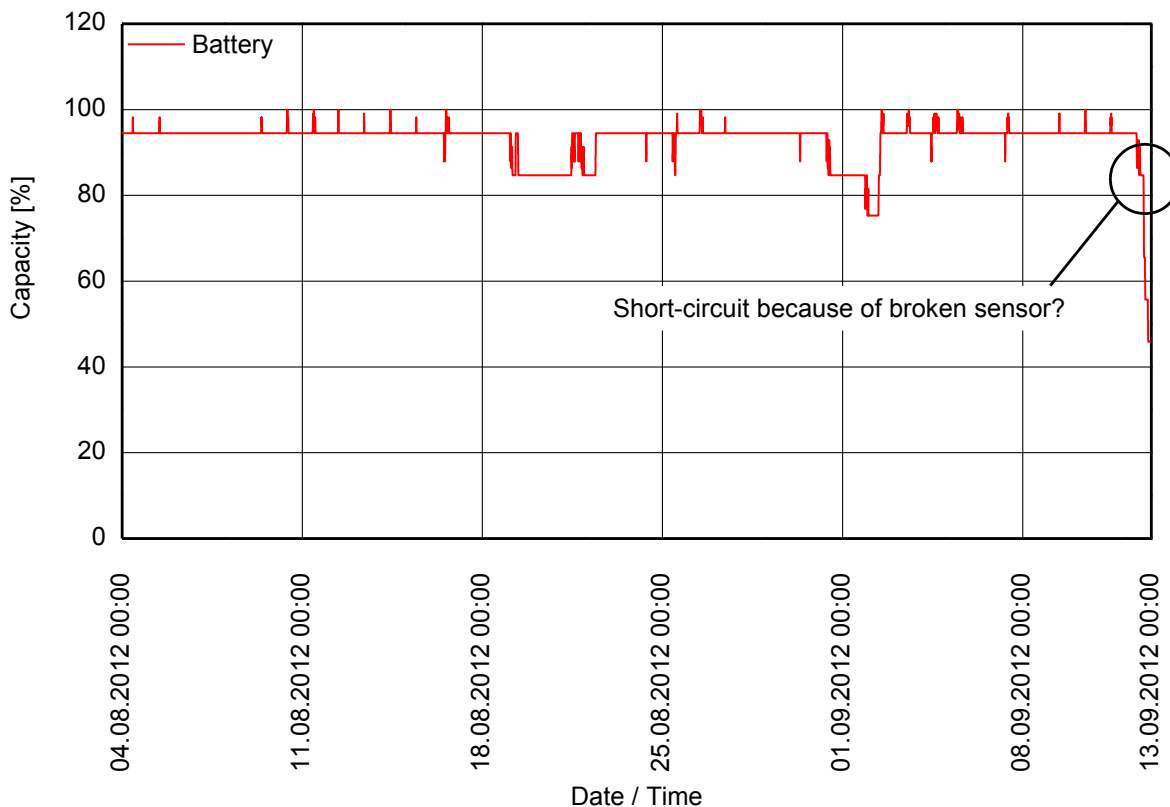


Figure 19 - Battery charge using just the solar panels during the real tests in Rauh window [by Ingo]

As a resume, the solar panels used can be extended to more or less panels, according to the window specific needs, such as climate region, orientation, etc.

The solar panels model is expected to be changed to fit different dimensions and have a better appearance, but the same electrical specifications should apply and in our opinion, the possibility for easy expandability should be a required feature, to solve the more difficult weather conditions.

2.4.11 The sensors

The window controller has 4 sensors coming out of the board as add-ons. See Figure 20 for the sensors position details.

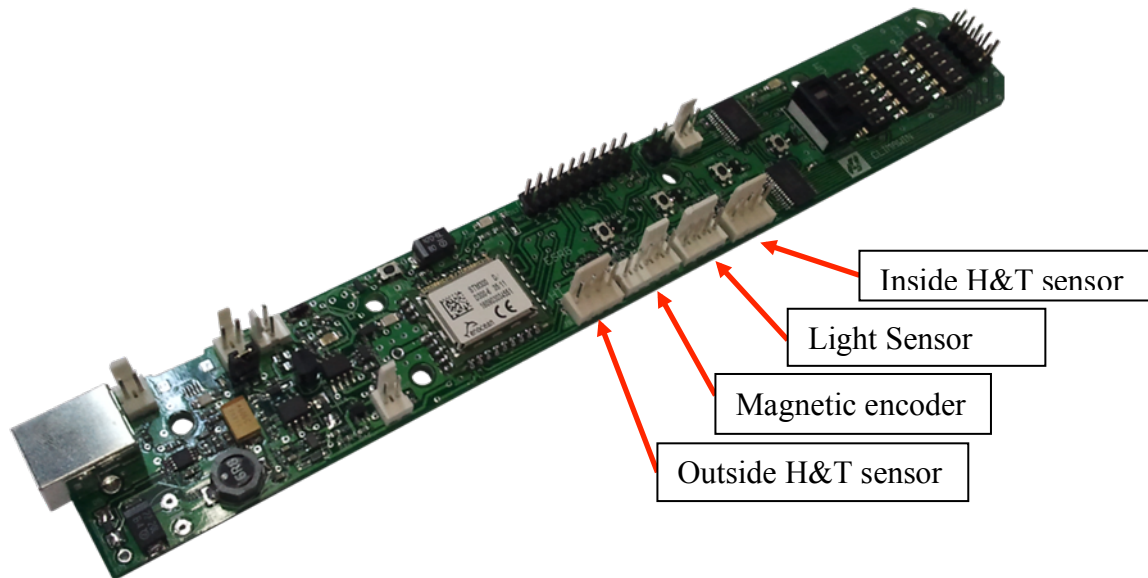


Figure 20 - Window controller with Sensors add-ons positions

The window controller will need to get the sensors data in order to execute the control algorithm.

The communications baud rate is not high, but even then, the smaller the cables, the better.

The encoder cable must be shielded because it will be lengthy and will be installed very close to the motors power cables which will induce significant noise to the sensor communication and power lines.

During the tests, we verified that since the PCB was being fixed with metallic screws, that affected the magnetic field direction. This led to angle misreading, thus,

The fixing method to hold the magnetic encoder PCB to the valve should be

The humidity and temperature sensors are installed inside a hole in the window frame. This hole represents a weak insulation point between both the outside and the gap, as well as between the gap and the window inside frame.

The sensors have been installed very close to the window gap vertical center, near the window controller board. This placement however needs to be analyzed and evaluated (probably by Aalborg), to find a way to avoid it or to compensate the readings. In our opinion, the software compensation is the worst option, because the T&H sensor gets the humidity value based on internal temperature compensation, and that temperature cannot be compensated by software.

The Figure 21 and Figure 22 show the difference between the temperature measure by a calibrated instrument and the value measured by the window sensor. As one can see, this difference is quite big and it will influence the threshold points defined in the configuration switches.

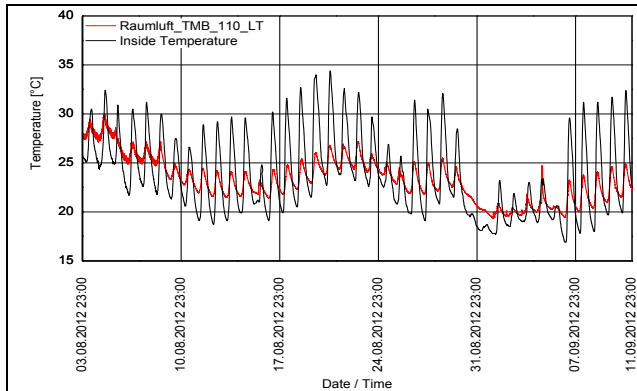


Figure 21 - Inside temperature: real and measured

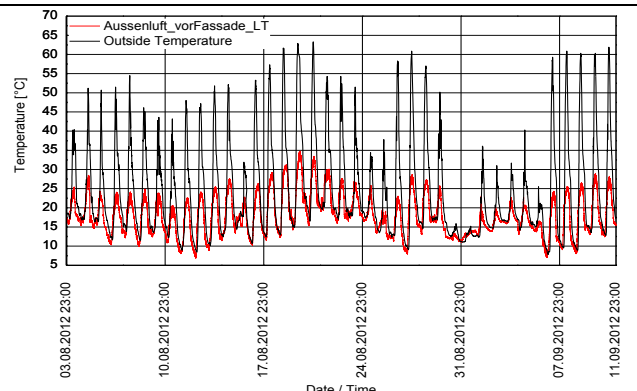


Figure 22 - Outside temperature: real and measured

Regarding the humidity we can also see differences (Figure 23). The red line is the real value and the black is the measured value.

As one can see in the Figure 24, the acquired light value is very accurate, since the temperature has no influence over the measured value. This sensor performance is very good.

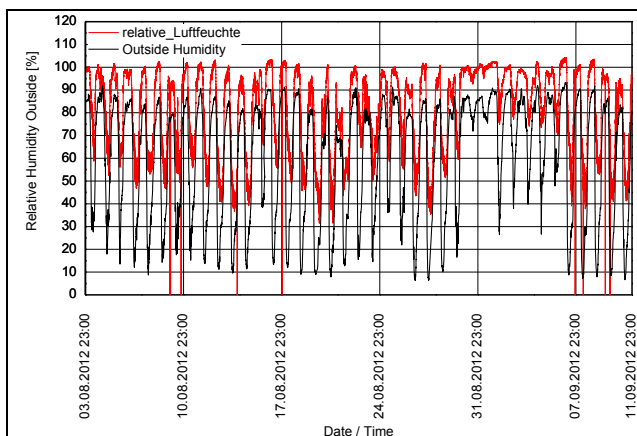


Figure 23 - Outside humidity: real and measured

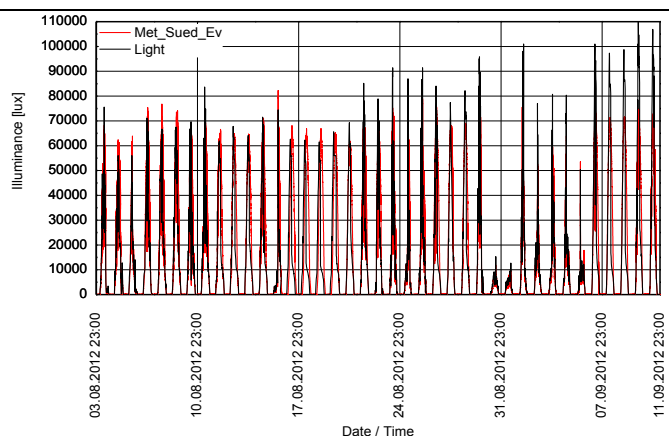


Figure 24 - Light: real and measured

2.4.12 The actuator circuit

The valve and blind motors are controlled by a separated actuator PCB that is responsible for the following features:

- Drive valve motor both ways;
- Protect the valve motor from over currents that may occur when the motor gets stuck either by mechanical failure or by reaching the mechanical end;
- Protect the valve motor from driving the motor both ways simultaneously;
- Step-up the battery voltage to 24V to suit the motor nominal voltage;
- Drive the blind motor both ways;
- Protect the blind motor from over currents that may occur when the motor gets stuck either by mechanical failure or by reaching the mechanical end;
- Protect the blind motor from driving the motor both ways simultaneously;

The actuator circuit PCB is shown in the Figure 25.

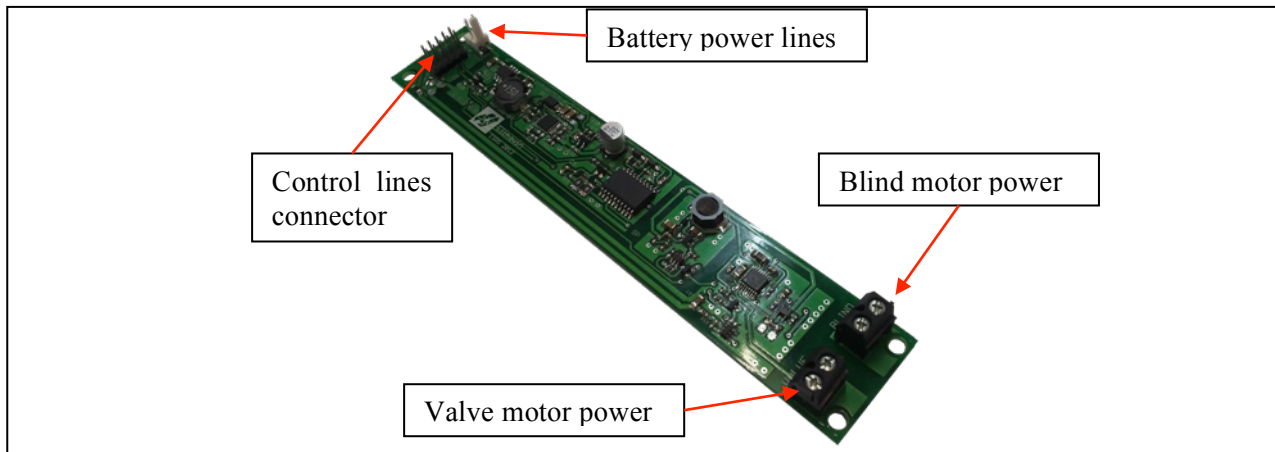


Figure 25 - Blind and valve motors controller

The battery power lines are a two-line connector to power the PCB directly from the connector CON_MOT (in the window controller), that has a small and robust connection to the battery. The Control lines connector is a 10-pin standard flat cable connector with the layout shown in the Figure 26.

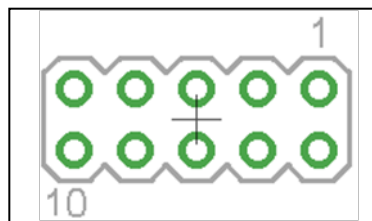


Figure 26 - Window controller power connector

The pin description is the following:

1. Move valve right signal
2. Move valve left signal
3. Move blind right signal
4. Move blind left signal
5. Valve motor stuck feedback signal
6. Blind motor stuck feedback signal
7. Power supply to power the circuit (3.3V regulated);
8. Power supply to power the circuit (3.3V regulated);
9. Ground
10. Ground

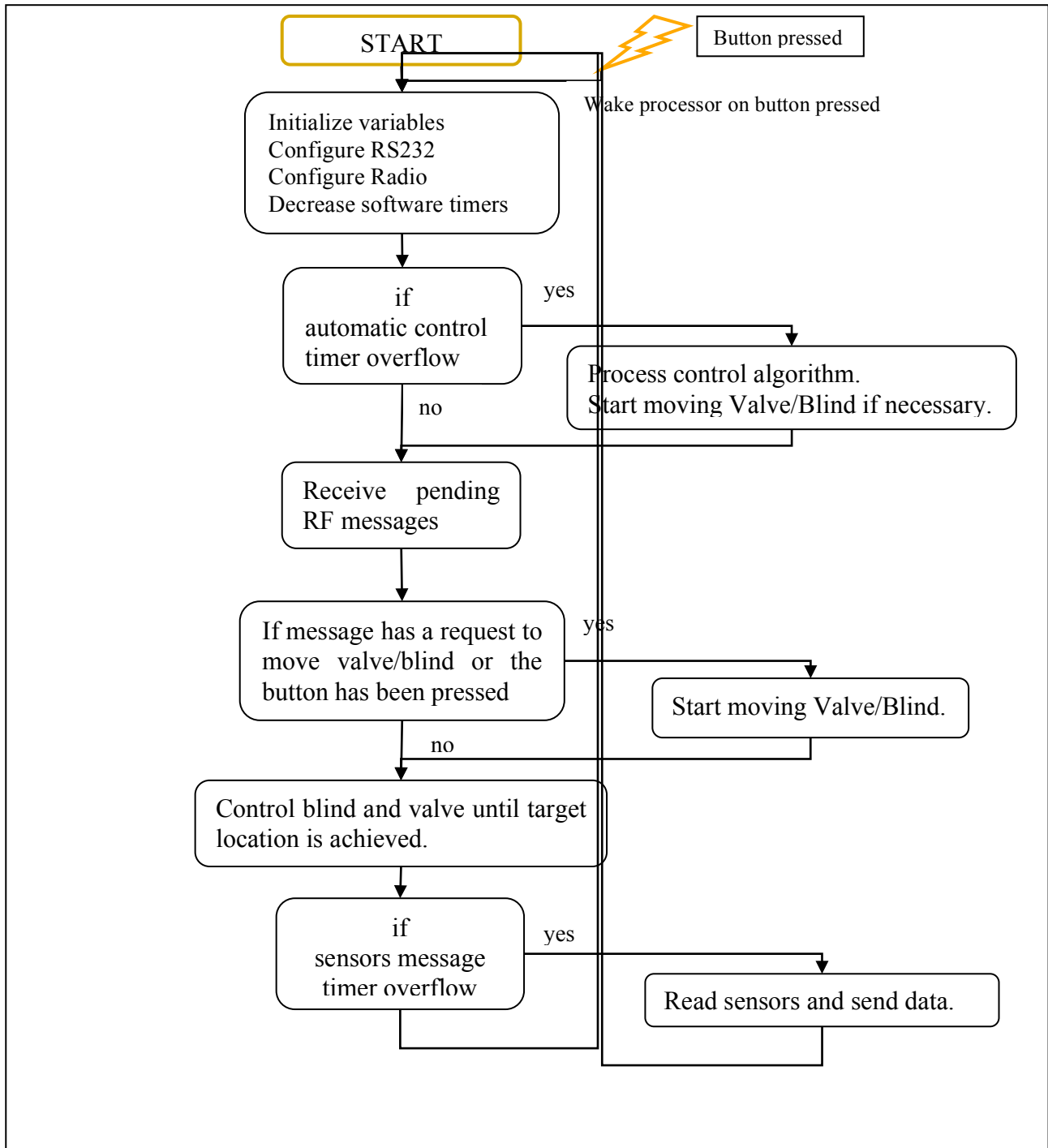
2.4.13 Firmware

The Climawin controller was programmed to save as much power as possible, while guaranteeing a response to the user and backbone requests, in a tolerable time frame.

In order to save power, the microcontroller is in deep sleep mode when it is not occupied moving the valve, the blind, accessing the sensorial information, or requesting for pending incoming messages.

In an idle condition, the window controller will sleep for 2 seconds, defined in the `STANDBY_MODE_WAKE_MS` macro.

The next flow chart shows the programs main structure.



After the wake from a reset or a deep sleep situation, the microcontroller will update its software timers and evaluate if it is time to apply the control algorithm. If so, it will decide in which position the valve and blind should go, and will apply that new desired position to the valve and blind position control tasks.

Then, the system will go check if any request occurred, either by a local input button or by a message received from the RF interface. If so, the desired position will be passed to the valve and blind position control once again.

After this gather of information is finished, the blind and valve tasks will be processes as a states machine and the system will check for user input, either from the local inputs or from the RF messages that may be received while processing. While the system is in this processing stage, the zone controller is accessed every 100ms (as defined in the `ACTIVE_MODE_WAKE_MS` macro) for a faster response to user requests. This is important to allow the user to stop the blind in any desired position, since with a larger period between messages claims, the system would take too long to react.

3 System Installation

The system installation is based on two steps:

1. Window electronics installation (on factory): This is where the window electronics parts are assembled, from plugging the sensors to the main controller PCB, the actuator PCB, battery, valve and test if every part is well assembled to complete the window installation;
2. Whole system installation and configuration (on site): This is when all the windows, zone controllers, CO2 sensors and rocker switches are installed on site.

First, there is a need to plan the placement for the components that may have some placement freedom, such as the zone controller, the rocker switches and the 3rd party CO2 sensors. A good radio placement planning can reduce the number of necessary repeaters, and will make the communications much more reliable.

The EnOcean Application Note 001 – “*EnOcean Wireless Systems – RANGE PLANNING GUIDE*” [1] is a great manual with many good tips on how to perform the radio planning for the system components.

3.1 How to install the system

The system learn procedure is the required step to create a custom device association, in other words, it is the method by which we put the system components “talking” to each other, following the pre-defined communication rules we want to establish.

The communications scheme is defined as a devices MAC addresses matrix, and it is stored in the zone controller internal memory.

The zone controller is the device responsible to forward the messages to the correct targets, according to that matrix.

The zone controller supports 3 zones, as defined in the `NUM_ZONES` macro, in the `main.h` file from the zone controller firmware.

This matrix is defined to have 3 windows, 1 CO2 sensor and 1 Rocker per zone. This data set is defined in the `LEARNED_SENSORS` structure, in the `main.h` file from the zone controller firmware, and can be easily changed to fit the most common situations, in order to get the most from the limited memory available at the microcontroller.

Let’s look at an example before describing how to do it.

Let’s assume that we have the following devices:

ZC1 – Zone Controller 1
 WC1 – Window controller 1
 WC2 – Window controller 2
 WC3 – Window controller 3
 CO2_1 – CO2 sensor 1
 CO2_2 – CO2 sensor 2
 RS1 – Rocker switch 1
 RS2 – Rocker Switch 2

And let us assume that zone controller ZC1 is already programmed with the following matrix:

	Window controller #1	Window Controller #2	Window Controller #3	CO2 sensor	Rocker switch
Zone #1	WC1	WC2	-----	CO2_1	RS1
Zone #2	WC1	-----	-----	-----	RS2
Zone #3	WC3	-----	-----	CO2_2	RS1
Zone #4	-----	-----	-----	-----	-----
Zone #5	-----	-----	-----	-----	-----

Every time the zone controller receives a RF message, it will evaluate each zone in the matrix and send the messages (from the CO2 sensor or from the rocker switch) to every window controller in the set.

So, if RS1 is pressed, WC1, WC2 (zone 1) and WC3 (zone 3) will receive the message.

When CO2_1 sends the information about its measurement, the zone controller will forward it to WC1 and WC2 (zone 1).

When the RS2 is pressed, only WC1 will receive the message (zone 2).

When CO2_2 send the information about its measurement, only WC3 will receive the message (zone 3).

The process of creating and editing this matrix is attained by using the interface available in all the devices, as described here:

- **Window Controller:** The learn button (Figure 11) and the processor active LED (Figure 12);
- **Zone Controller:** The 3 buttons available in the PCB(Figure 27) and the 7 segment display in the PCB;
- **3rd party CO2 sensors:** The device own learn button (see the device user manual for details);
- **Rocker switch:** Any rocker button will do;

In the center of this process is the zone controller itself.

The buttons and the display are used to insert the devices in the configuration matrix and to remove them.

The zone controller interface is so simples and limited, that the methods to edit the matrix can be resumed in a few options.

The menu has a timeout of only 5 seconds, as defined in the CO2_PERIODE_PERIODE_MS macro, in the userMenu.h file from the zone controller firmware. This value can be easily changed by changing the referred macro value. If the timeout occurs in any of the operations, restart from step 1.

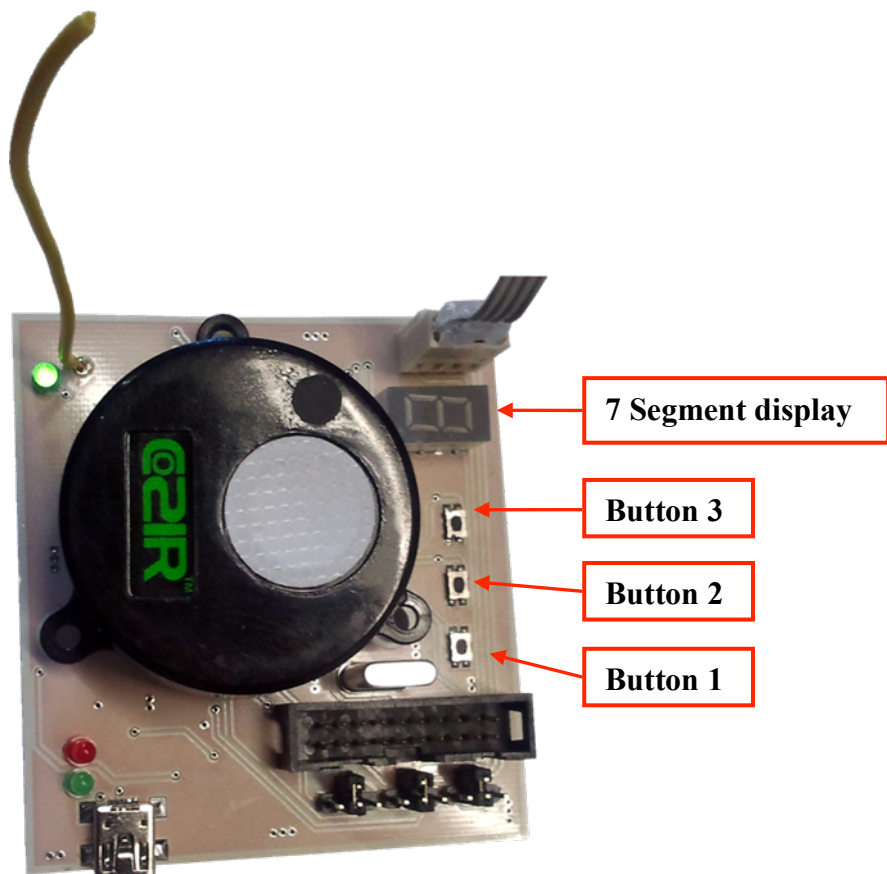


Figure 27 - Zone controller user interface details

3.1.1 Check if the zone has windows, the CO2 sensor and the rocker switch associated

1. Press Button 1
The display will show the zone to select. Pressing the Button 1 more often, will increase the zone to be selected.
2. Press Button 2
The zone that was being displayed is now selected. The number is now blinking, waiting for radio signals from a window learn button, CO2 learn button, or rocker switch button pressed.
The display number (blinking) represents the total number of blinds associated to this zone.
The dot has three possible meanings:
 - Dot OFF: There is no CO2 or Switch attached;
 - Dot blinking in phase with the number: There is a remote switch attached to this zone;
 - Dot blinking in phase opposed-phase with the number: There is a CO2 sensor attached to this zone;

Dot ON without blinking: There is both a CO2 and Rocker switch attached to this zone;

3.1.2 Erase a specific zone

1. Press Button 1
The display will show the zone to select. Pressing the Button 1 more often, will increase the zone to be selected.
2. Press Button 2
The zone that was being displayed is now selected.
The display number (blinking) represents the total number of blinds associated to this zone.
The dot has three possible meanings:
 - Dot OFF: There is no CO2 or Switch attached;
 - Dot blinking in phase with the number: There is a remote switch attached to this zone;
 - Dot blinking in phase opposed-phase with the number: There is a CO2 sensor attached to this zone;
 - Dot ON without blinking: There is both a CO2 and Rocker switch attached to this zone;
3. To clear the zone, keep pressing Button 2 for about 5 seconds, until the number flashing gets to zero and the dot is OFF. According to the display meaning, this means that the zone has no windows attached, as well as no CO2 and no rocker switch.

3.1.3 Insert/Remove a window into a specific zone

1. Press Button 1
The display will show the zone to select. Pressing the Button 1 more often, will increase the zone to be selected.
2. Press Button 2
The zone that was being displayed is now selected.
The display number (blinking) represents the total number of blinds associated to this zone.
3. Press Window Controller Learn Button
The zone controller blinking number will increase if the window was added or decrease if the window was removed from that matrix line. Note that the add/remove operation only applies to the selected zone.

3.1.4 Insert/Remove a CO2 sensor into a specific zone

1. Press Button 1
The display will show the zone to select. Pressing the Button 1 more often, will increase the zone to be selected.
 2. Press Button 2
The zone that was being displayed is now selected.
The display number (blinking) represents the total number of blinds associated to this zone.
 3. Press CO2 learn button.
This can be either the 3rd party CO2 sensor learn button or the Button 3 from the zone controller, in order to attach its own CO2 sensor to that zone.
When that happens, the dot will update, according to its programmed meaning:
-

Dot OFF: There is no CO2 or Switch attached;
 Dot blinking in phase with the number: There is a remote switch attached to this zone;
 Dot blinking in phase opposed-phase with the number: There is a CO2 sensor attached to this zone;
 Dot ON without blinking: There is both a CO2 and Rocker switch attached to this zone;

3.1.5 Insert/Remove a Rocker switch into a specific zone

1. Press Button 1
 The display will show the zone to select. Pressing the Button 1 more often, will increase the zone to be selected.
2. Press Button 2
 The zone that was being displayed is now selected.
 The display number (blinking) represents the total number of blinds associated to this zone.
3. Press any of the rocker switch button.
 When that happens, the dot will update, according to its programmed meaning:
 Dot OFF: There is no CO2 or Switch attached;
 Dot blinking in phase with the number: There is a remote switch attached to this zone;
 Dot blinking in phase opposed-phase with the number: There is a CO2 sensor attached to this zone;
 Dot ON without blinking: There is both a CO2 and Rocker switch attached to this zone;

4 Conclusion

The Climawin demonstration installation worked well for the purpose of testing the principle of operation and the feasibility of the product as a benefit for the energetic efficiency and consumer's life comfort.

The system is still in a prototype phase and there are several improvements and developments to be done, especially in the mechanical and user interface areas.

In terms of electronics, there is the necessity of adapting some of the components to fit the final production needs and certification.

Here are a few bullets of what can be done next:

- Creation of a new Enocean standard for the window;
 - Redesign the zone controller layout to fit the commercial enclosure demands;
 - Redesign the zone controller for the commercial enclosure demands;
 - Improve and automate the testing mechanisms for real production;
 - Test in real situations for some worst-case scenarios, like winter time and regions with big and frequent overcast periods;
 - Test the system for intensive operation over the mechanical parts, such as buttons.
-

9. EXPERIMENTAL VALIDATION AND CERTIFICATION

The experimental validation and certification includes tests of the CLIMAWIN ventilation system and tests performed by standardized test procedures. Specially designed tests and calculations were developed to prove functionality and to support calculations and simulations to get the energy efficiency of the window system.

In the beginning of the project the existing standards were proved for applicability to windows with ventilation functions and the preheating of incoming air. Amendments to the procedures of the relevant standards had been necessary for the determination of the thermal transmittance (U-value) and the total solar energy transmittance (g-value). The ventilation properties and acoustic tests could be done without changing the standard.

Two samples were tested from the company Horn and three samples from the company RAUH, see [Deliverable D9.1]. Only selected results are included in this report for illustration of the information available.

9.1 TEST PROGRAMME AND USED TEST STANDARDS

Standards and methods used and developed to determine the properties and performances for the ventilation windows are shown below.

Points with an arrow → show the tests, which had to be adapted to the new window or where new test procedures and facilities had to be developed. The detailed description of the test procedures you can find either in [Deliverable D9.1] or in the individual test reports.

- Ventilation EN 13141-1 (free ventilation)
- Water tightness, EN 1027/ EN 12208
- Air permeability, EN 1026 / EN 12207
- Resistance to wind load, EN 12211/ EN 12210
- Soft and body impact EN 13049
 - according to the window producer is not needed
- Operation forces EN 12046-1/ EN 13115
 - according to the window producer is not needed
- Acoustic Tests EN ISO 140-3 / EN ISO 717-1 , EN ISO 16032
- Thermal transmittance, EN ISO 12567-1 and EN ISO 10077-1 and 10077-2
 - Adaption of the standard to measurement of dynamic thermal behaviour
- Solar energy transmittance / (EN 410 / EN 13363 or calorimetric test) [20]
(dimension 1 m to 1 m incl. frame)
- → Adaption to dynamic thermal behaviour
- System description and advice for ITT, factory production control and CE-Marking has to be made by the producers with the help of Fraunhofer.
- Functionality and test of condensation behaviour
 - Functional testing in the climate chamber (IBP Stuttgart)
 - → Developing of test procedure
 - 2 tests of prototype windows “insitu” on free field house (IBP Holzkirchen) for calculation validation
 - → Developing a test procedure

- Energy balance
Energy balance calculation on the basis of the results of the “insitu” tests with TRNSYS [23]
→ Developing of a calculation model

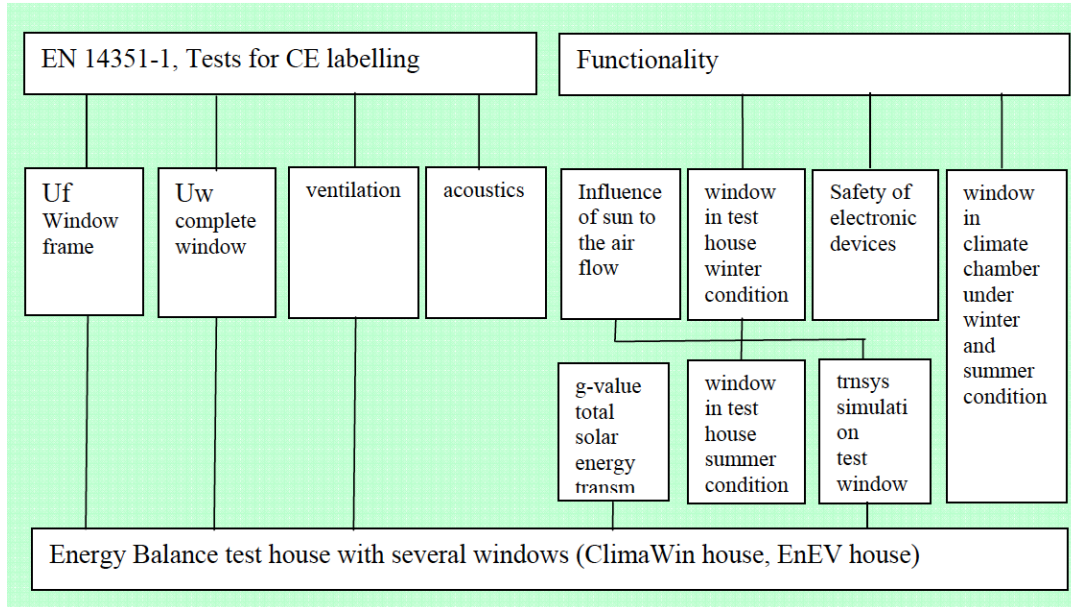


Figure 9.1. Test plan for validation and certification of the ventilation windows

9.2 CAPACITY OF VENTILATION SYSTEM

For the determination of the functionality of the ventilation system including the test of the condensation behaviour, the tests had been designed and performed in climate chambers as well as in a real test house.

Figure 9.2 shows the measured air flow rate as a function of pressure difference through the final prototype ventilation system implemented in the windows. Based on such a curve the number of ventilation units in each window can be determined, depending on the air flow rate needed and the reference pressure difference used in individual countries, see chapter 4.

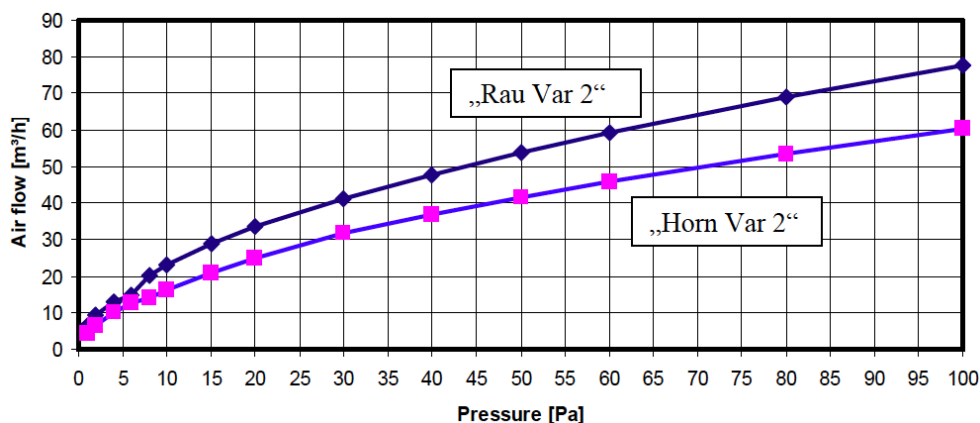


Figure 9.2. Air flow rate in l/ s measured at the final prototype “Horn Var 2” and “Rauh Var 2”, Ventilation system in heating mode (2 valves fully open, bypass closed)

The ventilation system has a good modular concept that the windows easily can be equipped with the right amount of valves according to the requirement for ventilation of the room. Thus, the indoor air quality needed to avoid moisture and health problems can be achieved using the ClimaWin-window as a system for natural ventilation or more precise in combination with house ventilation system.

Because the concept of the system is to bring additional air into the room the valves should be advanced with a non-return function to avoid air leaving the room through the system by use as a natural ventilation system.

9.3 HEAT TRANSMISSION – U-VALUE OF FRAME

The calculated U_f -values of the window frame dropped to $0.6 \text{ W/(m}^2\text{K)}$ but were much higher in the area of the mounted valves in the sash as illustrated in figure 9.3. The U_w -value of the whole windows therefore were higher with a value of $0.95 \text{ W/(m}^2\text{K)}$ and $1.1 \text{ W/(m}^2\text{K)}$. But this can be easily improved by triple glazing and insulated boxes for the valves and electronic devices installed in the window sashes.

Calculation according EN ISO 10077-2

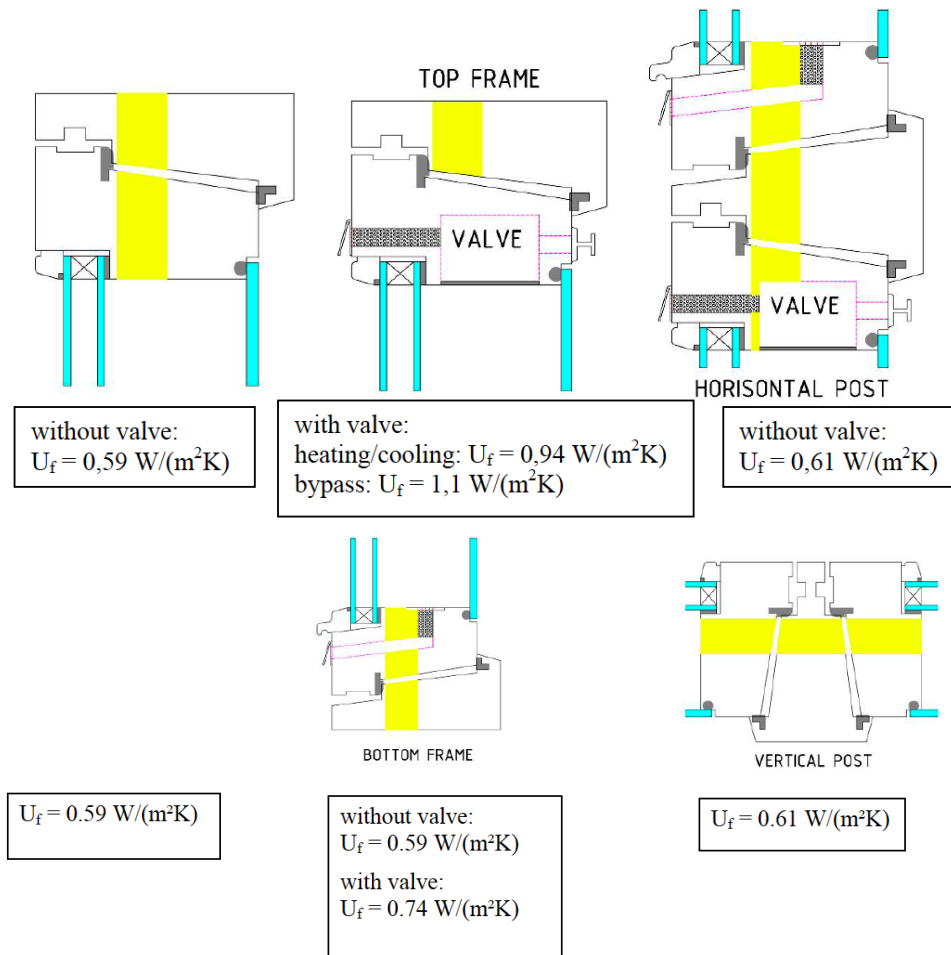


Figure 9.3. U_{frame} calculation for Horn Var 2 according to EN ISO 10077-2 (treated wood $0,12 \text{ W/(mK)}$) with 15 mm thermal insulation $PU \ 0,025 \text{ W/(mK)}$).

9.4 TOTAL SOLAR ENERGY TRANSMISSION

Test of the total solar energy transmittance (g-value) in a calorimetric test facility allows realistic energetic assessment of glazing systems and system combinations, e. g. glazing with internal shading system or like in this case for ventilated windows. The measurements were made with normal incident radiation. The irradiance level on the sample was about 500 W/m². The results are combined in Figure 9.4 and 9.5.

Air flow rate	internal temperature	External temperature	air temperature gap		Total energy transmittance g-value
			inlet	outlet	
l/s	°C	°C	°C	°C	-
0	26	25	31	38	0,54 ± 0,05
1,61	25	25	27	36	0,51 ± 0,05
2,39	25	25	26	33	0,50 ± 0,05
4,06	25	25	26	30	0,50 ± 0,05

Figure 9.4. Determination of total energy transmittance in dependence of the air flow rate in the air gap for Horn Var. 2.

Air flow rate	internal temperature	External temperature	air temperature gap		Total energy transmittance g-value
			inlet	outlet	
l/s	°C	°C	°C	°C	-
with retracted venetian blinds					
0	25	25	34	35	0,48 ± 0,04
1,59	25	25	31	37	0,47 ± 0,04
2,42	25	25	31	35	0,47 ± 0,04
4,07	25	25	31	33	0,47 ± 0,04
with closed venetian blinds					
0	22	25	34	38	0,07 ± 0,01
2,46	21	25	31	40	0,05 ± 0,01

Figure 9.5. Determination of total energy transmittance in dependence of the air flow rate in the air gap for RAUH Var. 2.

The results show that the total solar energy transmission depend on the air flow rate. Especially for the situation with closed blinds the air flow in the cooling mode helps decreasing the energy transmittance with more than 25%.

9.5 ACOUSTICAL PROPERTIES

Acoustical properties were tested for the different ventilation modes for the different prototype windows.

The tests showed that the acoustic properties of the final prototypes (Var 2) were not sufficient with results between $R_w = 29$ dB up 35. On a further developed window (RAUH Var. 3) results showed that up to $R_w = 40$ dB in the closed position could be achieved. Figure 9.6 and 9.7 gives as an example the obtained values in the acoustical tests for RAUH Var. 3.

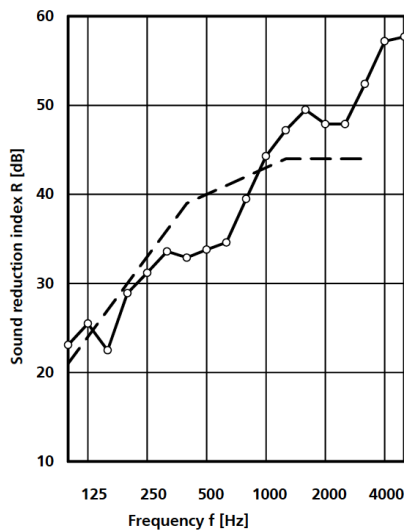


Figure 9.6. For RAUH Var. 3 in closed mode the weighted sound reduction index according to DIN EN ISO 10140-2: 2010 and the spectrum adaption terms calculated acc. to DIN EN ISO 717-1: 2006 amount to $R_w (C; C_{tr}; C_{100-5000}; C_{tr, 100-5000}) = 40 (-2; -5; -1; -5)$ dB.

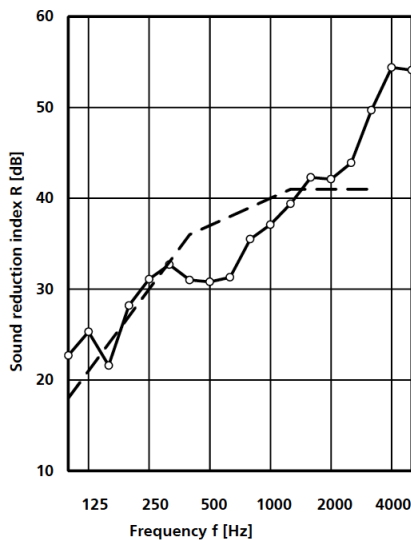


Figure 9.7. For RAUH Var. 3 in heating mode the weighted sound reduction index according to DIN EN ISO 10140-2: 2010 and the spectrum adaption terms calculated acc. to DIN EN ISO 717-1: 2006 amount to $R_w (C; C_{tr}; C_{100-5000}; C_{tr, 100-5000}) = 37 (-1; -4; 0; -4)$ dB.

9.6 FUNCTIONAL TESTS

The tests were intended to test the functionality of the CLIMAWIN system including electronically controlled valves for ventilation control and preheating of the incoming air in winter situation. With the same tests the hygrothermal behaviour of the window system was checked to find out if condensation or other problems for the user or possible damages to the building have to be expected.

The results of the functional tests at the final prototypes in the climate chamber at various winter and summer climates showed that the preheating of the additional air between two layers of glazing works as well as the electronically controlled ventilation valves.

The control in dependence of inside temperature, relative humidity and CO₂ level led to the right position of the valves “cooling” or “heating” mode according to the measured values.

One problem occurred that the sensors for temperature and relative humidity which were installed in the window sash deviate from the real temperature and relative humidity inside because of their position in the sash and not in the room. This has to be corrected.

The CO₂ and light measuring was working well. The remote control of the blinds in the air gap worked as well as the wireless connection between electronic components installed somewhere in the test room and the electronic devices like the motor for the valves and the sensors in the window sash.

9.7 IN-SITU TESTING

Two prototypes of the CLIMAWIN-window were installed in a test house at the outdoor test facility of the Fraunhofer Institute for Building Physics, Holzkirchen Branch. The prototype "Horn Var 1" was placed in the test house during the winter period 2011 / 2012, the prototype "RAUH Var 2" during summer 2012.

The first test period was mainly used to get measurement data for the validation of a transient simulation model of the test house including the air flow through the window in the heating mode. The test room was operated by different exhaust air flow rates in different measurement periods in order to get different boundary conditions for the preheating of the air gap of the window.

The window showed a good energy performance in winter compared to a normal window with similar U- and g-value. The in-situ measurements during the winter period also showed that the higher the exhaust flow rate the lower is the temperature increase in the air gap according to the ambient temperature. A significant temperature layering in the air gap can only be recognized by means of mechanical ventilation.

The second test period was dedicated to practical aspects concerning the prototype Rauh Var 2 which had been implemented the whole technical and electronic equipment necessary to control the valves of the window. It was the issue of the quality of the integrated sensors and the evaluation of the control algorithm.

Comparisons between the sensors and the approximately accurate in-situ sensors showed a considerable discrepancy which primarily must be ascribed to the mounting of the sensors in the window frame affecting them by its absorption and emission of radiance.

The function of the control algorithm can be mostly followed; however, there can be registered valve changes that cannot be assigned to thresholds and the definitions in the code of the control algorithm. On the basis of the findings during the summer measurements several suggestions are derived for improvements in the further development of the system.

References

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- [6] Hans Erhorn (2007). BESTFACADE WP 4 report 'Simple calculation method'. Fraunhofer Institute for Building Physics (IBP), Stuttgart, Germany.

Appendix

OVERVIEW OF TECHNICAL REPORTS, PRESENTATIONS AND OTHER RESOURCES OF THE CLIMAWIN PROJECT.

No	WP	Author	Document type	File name	Website location
	-	AAU	Report	Technical Summary	
	-	AAU	Presentation	Dissemination presentation at final meeting in Dublin September 2012 AAU Per	Presentation
	-	All	Presentation	Review meeting presentation made for REA MAIN – v5	Presentation
	-	AAU	Presentation	Review of workplan incl. Wp2,3,4,5,6,7,8.PH	Presentation
	-	AAU	Presentation	Measurement Programme.PH	Presentation
	-	AAU	Presentation	Kick-Off Meeting nov 2010.PH	Presentation
	3	AAU	Deliverable 3.1	CLIMAWIN report on functional requirements, envelope definition and calculation	Workpackages/wp3
	4	AAU	Deliverable 4.1-2	Notional system design and calculation methodology ver5	Workpackages/wp4
	4	AAU	Deliverable 4.3	Climawin electronics integration report	Workpackages/wp4
	4	AAU	Deliverable 4.4	Climawin product design report	Workpackages/wp4
	4	AAU	Deliverable 4.5	Climawin development of simple calculation tool	Workpackages/wp4
	4	AAU	Excel Tool	Climawin engine calculation	Templates
	4	AAU	Report	Window Frame U-values Full Report Horn	Presentation
	4	AAU	Report	Simple calculation method report April 22	Presentation
	4	AAU	Presentation	Glazing and Fram Work_Stansted_Jan2012_AAU	Presentation
	4	AAU	Presentation	Window construction D6_1_26Jun2011_OL	Presentation

No	WP	Author	Document type	File name	Website location
	5	AAU	Deliverable 5.1	Ventilation mechanism prototype for testing by AAU	Workpackages/wp5
	5	DI	Presentation	M12 DI 2011-09-29_Vent_concepts	Presentation
	6	AAU	Deliverable 6.1	Climawin window construction incl. glazing	Workpackages/wp6
	6	AAU	Excel Spreadsheet		
	6	AAU	Deliverable 6.2	Climawin prototype of combined solar shading – night blind element	Workpackages/wp6
	6	AAU	Deliverable 6.3	Climawin measurements on the performance of solar shading and night blind	Workpackages/wp6
	6	AAU	Presentation	Climawin project presentation Hicham_AAU	Presentation
	6	AAU	Report	Climawin Project Blind Experimental Report	Presentation
	7	UM	Deliverable 7.1	Climawin full control system architecture, control and specifications of system	Workpackages/wp7
	7	UM	Deliverable 7.2	Climawin printed circuit board schematics and prototype	Workpackages/wp7
	7	UM	Deliverable 7.3	Climawin software for PC to communicate with the developed hardware	Workpackages/wp7
	7	UM	Presentation	Meeting presentation – UM September 2012_Dublin	Presentation
	7	UM	Presentation	Meeting presentation – UM April 2012 Guimaraes	Presentation
	7	UM	Presentation	Meeting presentation – UM January Stansted	Presentation
	7	UM	Presentation	M12 Meeting presentation – UM September Bruxells	Presentation
	7	UM	Presentation	Meeting presentation – UM June Stuttgart	Presentation
	7	UM	Presentation	WP7 Climawin presentation Kick-off meeting UM	Presentation

No	WP	Author	Document type	File name	Website location
	8	HO	Deliverable 8.1	Climawin final window prototype	Workpackages/wp8
	8	UM	Deliverable 8.2	Climawin report on sensor, RFBT integration and product design	Workpackages/wp8
	9	Fraunh	Test report	IBP-AK-Rauh-P-BA-242-2012e-Acoustic	Workpackages/wp9
	9	Fraunh	Test report	P07-229-2012-Rauh-e-Uf	Workpackages/wp9
	9	Fraunh	Test report	P07-227-2012-Horn-e-Uf	Workpackages/wp9
	9	Fraunh	Test report	P06-223-2012-Rauh-e-air-water-wind-ventilation	Workpackages/wp9
	9	Fraunh	Test report	P06-222-2012-Horn-e-air-water-wind-ventilation	Workpackages/wp9
	9	Fraunh	Test report	P05-228-2012-Rauh-e-Uw	Workpackages/wp9
	9	Fraunh	Test report	P05-226-2012-Horn-e-Uw	Workpackages/wp9
	9	Fraunh	Test report	ISE-Rauh-TAG3-UA-1210-E05-26Okt12-jl-total energy transmittance	Workpackages/wp9
	9	Fraunh	Test report	ISE-Horn-TAG3-UA-1210-E04-26Okt12-jl-total energy transmittance	Workpackages/wp9
	9	Fraunh	Presentation	2012_04_16_ClimaWin_si	Presentation
	9	Fraunh	Presentation	M12 Fraunhofer 2011_09_29_Climawin	Presentation
	9	Fraunh	Presentation	ClimaWin-27-Juni-Stuttgart-2011-Ze1-kurz	Presentation
	9	Fraunh	Presentation	WP9 Presentation Kick-off meeting Fraunhofer	Presentation
	9	Fraunh	Deliverable 9.1	Final CLIMAWIN Test Report	Workpackages/wp9

